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NATURAL AND MODIFIED POCOSINS:

Literature Synthesis and Management Options

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NATURAL AND MODIFIED POCOSINS: LITERATURE SYNTHESIS AND MANAGEMENT OPTIONS

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PREFACE

Pocosins are natural ecosystems in transition to human use. Historically, their wetland character and impenetrable vegetation have allowed only moderate management, primarily forestry. Recently new technology and increased demand for fiber, food, and energy have made pocosin development for peat mining economically feasible, and development for forestry and agriculture commonplace. Peat mining methods have been developed, and large commercial peat mines will be a reality in the near future. As a result, natural pocosins are dwindling rapidly.

There is little understanding of the ecological functions and values of natural pocosins or of the environmental problems caused by pocosin development. What few data exist have, for the most part, appeared in the last decade, allowing only limited synthesis.

Better understanding of pocosins and the impacts caused by pocosin development is the key to striking a proper balance between pocosin alteration and preservation. Part 1 of this document synthesizes the literature concerning pocosin origin, geographical distribution, ecological characters, historical and current human use, and value for water purification and wildlife management. Where possible, data from pocosins or related Southeastern freshwater wetlands were used. However, it was often necessary to use information from unrelated systems. The first and second chapters introduce the document and characterize natural pocosins. Chapter 3 documents the history, extent, and techniques of pocosin development. Chapters 4 through 7 assess various environmental impacts of pocosins alteration. Part 2 presents management options. The first chapter of Part 2 considers regional management as a tool for effective land management. The second chapter of Part 2 analyzes water management from on-site and off-site perspectives. The third chapter of Part 2 summarizes current ideas concerning wildlife management and provides wildlife management recommendations by land-use type and species.

This document will assist a wide spectrum of users who have an interest in the wetlands of the Southeast. Sections concerning wildlife and water management on small and large farms and commercial forests are included primarily for individual and corporate landowners. To address the often quite different needs of State or Federal wildlife and natural resources officials, sections are included on regional management, management of wildlife on natural forest-land refuges, and management for specific important coastal plain wetland species. The broader sections are intended to promote a sense of regional responsibility and interdependence among different landowners. Finally, this document is intended for anyone interested in wildlife or environmentally oriented stewardship of our renewable resources.

Any questions or comments about or requests for this publication should be directed to:

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EXECUTIVE SUMMARY

Pocosins are freshwater wetlands found extensively in the lower coastal plains of Virginia, North Carolina, and South Carolina. Their vegetation is characterized by tangled masses of lethery-leaved shrubs overtopped by pond pines and/or bay trees. They have poor drainage with long periods of saturation and soils that vary from mineral to deep organic. Stature and composition of vegetation often vary due to the influences of low nutrient availability and fire. As a result, an area recognized as pocosin might be classified as any of the following: palustrine, scrub/shrub, broad-leaved evergreen, titi-honeycup (*Cyrilla-Zenobia*) wetland; palustrine, forested needle-leaved evergreen, pond pine (*Pinus serotina*) wetland; or palustrine, forested, broad-leaved evergreen, sweet bay - red bay - loblolly bay (*Magnolia virginiana-Persea-Gordonia*) wetland.

Pocosins have always been used for low intensity timber production, and some were converted to farms many years ago. In recent years, however, alteration of pocosins has accelerated because investors have seen potential for expanding agriculture and silviculture into these relatively undeveloped and inexpensive lands. In 1962, natural or only slightly modified pocosins in North Carolina occupied 907,000 ha (2,240,000 ac); but by 1979, natural pocosins in North Carolina occupied 281,000 ha (695,000 ac), about 31% of that present in 1962.

Approximately 60% of all pocosin is owned by groups with interests in timber production (44% by major timber companies and 18% as State or National forest). Large corporate farms presently own 21%, a considerable proportional increase caused by the transfer of nearly 202,000 ha (500,000 ac) of corporate forestland to large-scale agriculture in the early 1970's. Private landholders own 12% with the remaining 5% owned by various wildlife agencies or conservation groups.

Peat mining is a new use for some pocosins. Permits have been issued to mine 11,000 ha (27,000 ac) in North Carolina as of 1982, and the state's first peat-fired methanol production plant is being constructed south of Lake Phelps on the Albemarle-Pamlico Peninsula.

Natural pocosins serve important functions of wildlife habitat (particularly for diminishing populations of black bear), carbon storage, and water purification, retention, and storage. These functions may be disrupted by development.

The quality, quantity, and pattern of delivery of runoff reaching estuaries adjacent to pocosins change substantially with development, particularly runoff associated with agriculture. Clear evidence for an increase in total annual runoff is lacking. However, peak discharges of runoff following high rainfall are greatly intensified, resulting in delivery of large pulses of fresh water to estuaries. Percent increases of nitrogen in runoff are very large, although absolute quantities remain small compared to runoff from other agricultural regions. Fluxes of phosphorus resulting from fertilization of organic soils are greatly increased because of the low phosphorus retention of these soils. The impact of pesticides in runoff from agricultural development is uncertain. Discharge of coliform bacteria from developed organic soils, both in pasture and crops, is increased. Impacts on aquatic biota are most evident when discharge is delivered to small creeks and secondary estuaries which serve as habitat for sensitive juvenile organisms. For example, shrimp productivity has been shown to decrease with pulses of freshwater discharge. Although evidence specific to pocosin regions is limited, experience elsewhere has shown that the kinds of drainage and land development now taking place in pocosin regions can lead to serious eutrophication in downstream water. The Chowan River basin of North Carolina and the Kissimmee River basin of Florida are two examples. Broad-scale studies are recommended for pocosin regions to develop models for assessing the cumulative impacts from numerous local changes in water quality.

Various methods for treatment of runoff from developed pocosins have been proposed or tried experimentally. One current idea is the use of wetlands as filters. This concept has shown at least partial success in small-scale experimental applications. However, neither its effectiveness nor the potential for detrimental wetland changes have been assessed for filter areas receiving continual, large-scale agricultural drainage. Other schemes which merit consideration include diversion of drainage away from nursery areas to less sensitive parts of estuaries, use of impoundments and artificial marshes as treatment areas and sequential passage of discharge through various types of managed and natural systems. Setting aside a certain minimum percentage of land appears to be necessary for land treatment methods to work effectively. In any of these schemes, careful planning will be important to success; costs and benefits to public resources as well as economic incentives to private landowners will need to be taken into account. Further experimental trials involving cooperation between agencies of federal, state, and local governments and private landowners may be necessary before far-reaching recommendations are issued.

Although pocosins furnish food, cover, and water for fish and wildlife, it is generally accepted that they are not as productive as other forested wetlands or uplands. However, these latter habitats have often been converted to human use. Thus, pocosins constitute a large percentage of remaining natural or semi-natural forested land and are becoming increasingly important to wildlife of the region. Pocosins and pocosin edges provide some food and water for many non-game species and represent much of the remaining habitat for species which are intolerant of edge/field habitat or need seclusion. Pocosins currently serve as habitat islands for many species with black bear being the most prominent example. Pocosins serve as water-filters and provide colored, acid water of high quality to adjacent streams and estuaries which contain numerous sport and commercial fish species.

When natural pocosins are altered, there are several impacts on fish and wildlife. Land clearing reduces total acreage of wildlife habitat and dissects habitat into islands resulting in lower wildlife production and diversity. Aquatic habitat and water quality may be altered by construction of artificial drainage systems, channelization of streams, and siltation in all natural and artificial drainage networks. Constant human activity and noise may adversely affect many wildlife species with low tolerance for disturbance.

Recommendations for management of alligator, bear, deer, dove, fish, furbearers, quail, rabbit, red-cockaded woodpecker, and waterfowl are discussed individually. In addition, there are two general recommendations for habitat management of fish and wildlife in pocosins. First, a coordinated system of natural pocosin refuges should be organized for those species such as black bear which do poorly in edge or human-dominated habitats. A refuge of 20,000 ha (50,000 ac) should sustain a huntable population of black bear. All refuges should have controlled development, access, and hunting. Second, managers of developed pocosins or those currently being developed should institute conservation oriented techniques of water and wildlife management to mitigate losses of fish and wildlife habitat. Recommended techniques include: leaving or encouraging blocks of natural habitat of 8 ha (20 ac) or more in areas where deep organic soil is unsuitable for agriculture or forestry; leaving or encouraging wildlife corridors at least 30 m (100 ft) wide along roads, canals, and field edges; planting windbreaks along roads and ditches to prevent soil erosion; leaving brush piles and windrows in fields and at field edges for wilflife cover; encouraging or planting crops and natural wildlife foods along edges or in field corners or margins; building nesting structures to encourage specific species; and building impoundments to provide habitat for waterfowl and fish.

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PART I

LITERATURE SYNTHESIS

CHAPTER I. INTRODUCTION

Pocosin is the traditional name for a unique type of fire-adapted shrubby wetlands found on the Atlantic Coastal Plain from Virginia to Georgia but most extensively developed in North Carolina. In 1962, pocosins covered 907,000 ha (2,240,000 ac) in North Carolina and accounted for about 54% of the state's freshwater wetlands (Wilson 1962).

Until recently commercial development in pocosins was limited and the pace of development slow. Despite logging and some conversion to pine plantation or agriculture, most pocosins, particularly those with deep organic soils, were thought to be almost worthless for most commercial purposes. Pocosins were also considered marginal for many species of wildlife. With little open water, their value for waterfowl seemed negligible; and because of their dense vegetation and absence of favored forage plants, they were historically thought to be poor habitat for large animals like deer. Recently, however, pocosin development has become economically attractive. In the early 1970's, higher commodity prices provided financial incentive to increase agricultural acreages, and pocosins represented a significant remaining portion of undeveloped land on the mid-Atlantic coast. Furthermore, better techniques of drainage and land clearing and an improved understanding of the character and management of pocosin soils make it likely that recent expansions of agriculture and forestry into pocosins will succeed where earlier attempts failed. Even with modern techniques, pocosins with extremely deep organic soils have not proven amenable to either forestry or agriculture. Now, however, these former deep peat "wastelands" are being seen as a valuable energy resource with mining permits granted to several companies and some experimental peat mining underway.

The striking development of pocosins in the last two decades (Figures 1 and 2) coupled with the prospect for future changes has alarmed many observers, particularly those knowledgeable of wetland functions and values. During the 1960's these values were well-documented, and the public's perception of wetlands as wasteland began to change. Now we know that wetlands may have such important life-sustaining functions as biological productivity, water storage, flood protection, aquifer recharge, nutrient and sediment removal, carbon storage, and detritus output (Good et al. 1978, Greeson et al. 1979). Further, wetlands do not function in isolation but instead provide vital connecting links between uplands and aquatic systems. Wetland functions are frequently lost when wetlands are altered, and the present massive scale of pocosin conversion is attracting concern for the possibility of detrimental impacts that cannot be reversed.

Pocosins are among the last remote regions of eastern North Carolina. Many lack roads; and, even when present, the tangled vegetation makes it difficult to penetrate the underbrush for more than a few steps. This has prevented most hunters from venturing deeply into pocosins, but it has also greatly hampered attempts by game managers to collect accurate wildlife data. Even so, it is obvious that some species, like black bear, have sought pocosins as a final refuge (Wilbur 1981). If pocosins are not managed properly, the adverse effects on bear and other species in eastern North Carolina could be severe.

No matter what their benefits as natural systems, the conversion of pocosins to farms, pine plantations, and peat mines will continue. To assure the survival of certain species, it will be necessary to both preserve some natural pocosins and use sound wildlife management practices in areas that are developed for commercial use. The purpose of this manual is to provide a review of the literature on pocosins (Part 1) and to describe a variety of water and wildlife management techniques that are adaptable to the special problems and conditions that exist in both natural and converted pocosins (Part 2). This information has been collected for use by a wide range of technical and administrative officials and private users who will play key roles in decisions affecting natural and modified pocosins and fish and wildlife populations.

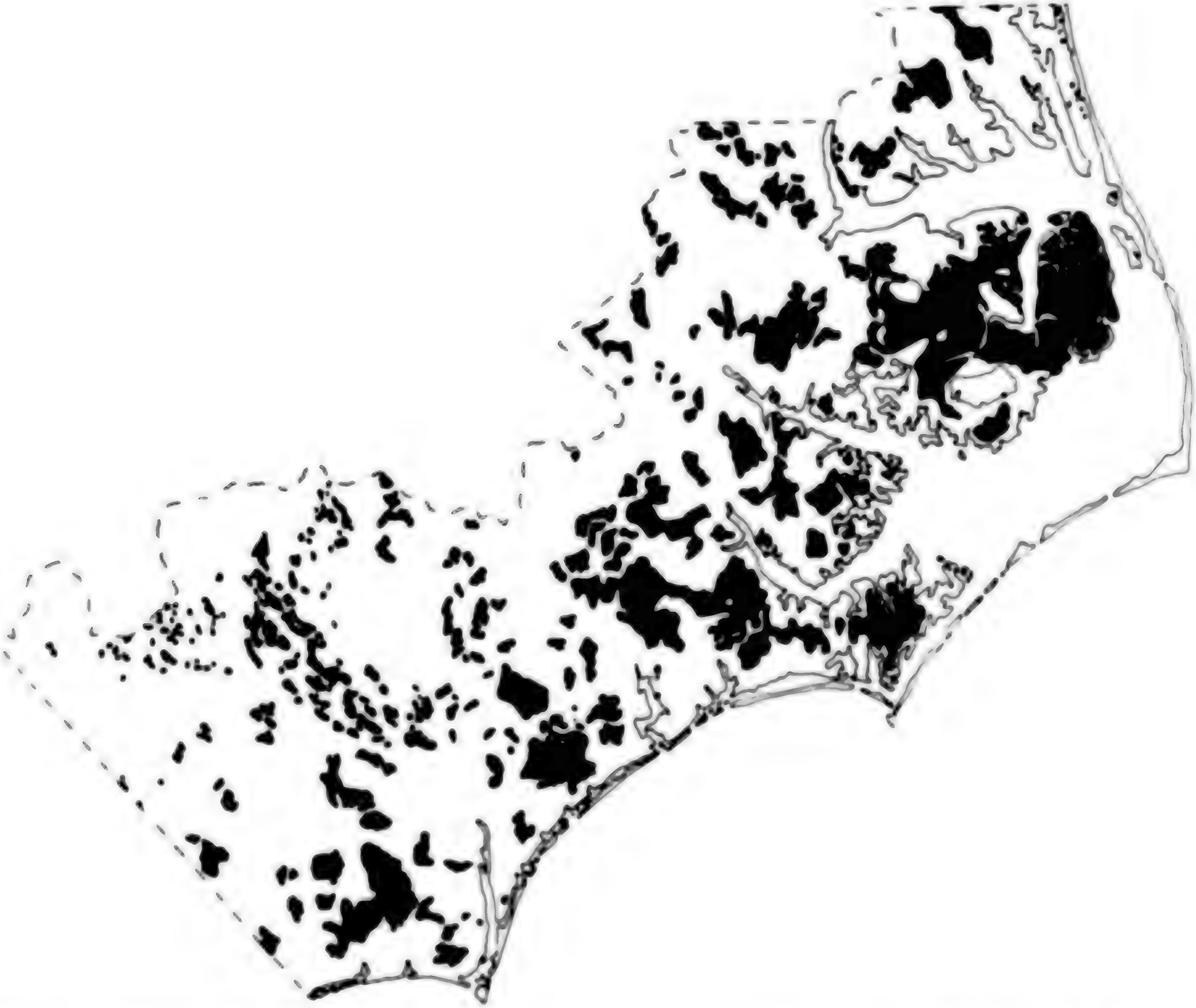

Figure 1. Extent of natural or slightly modified pocosin in 1962 (adapted from Richardson et al. 1981).

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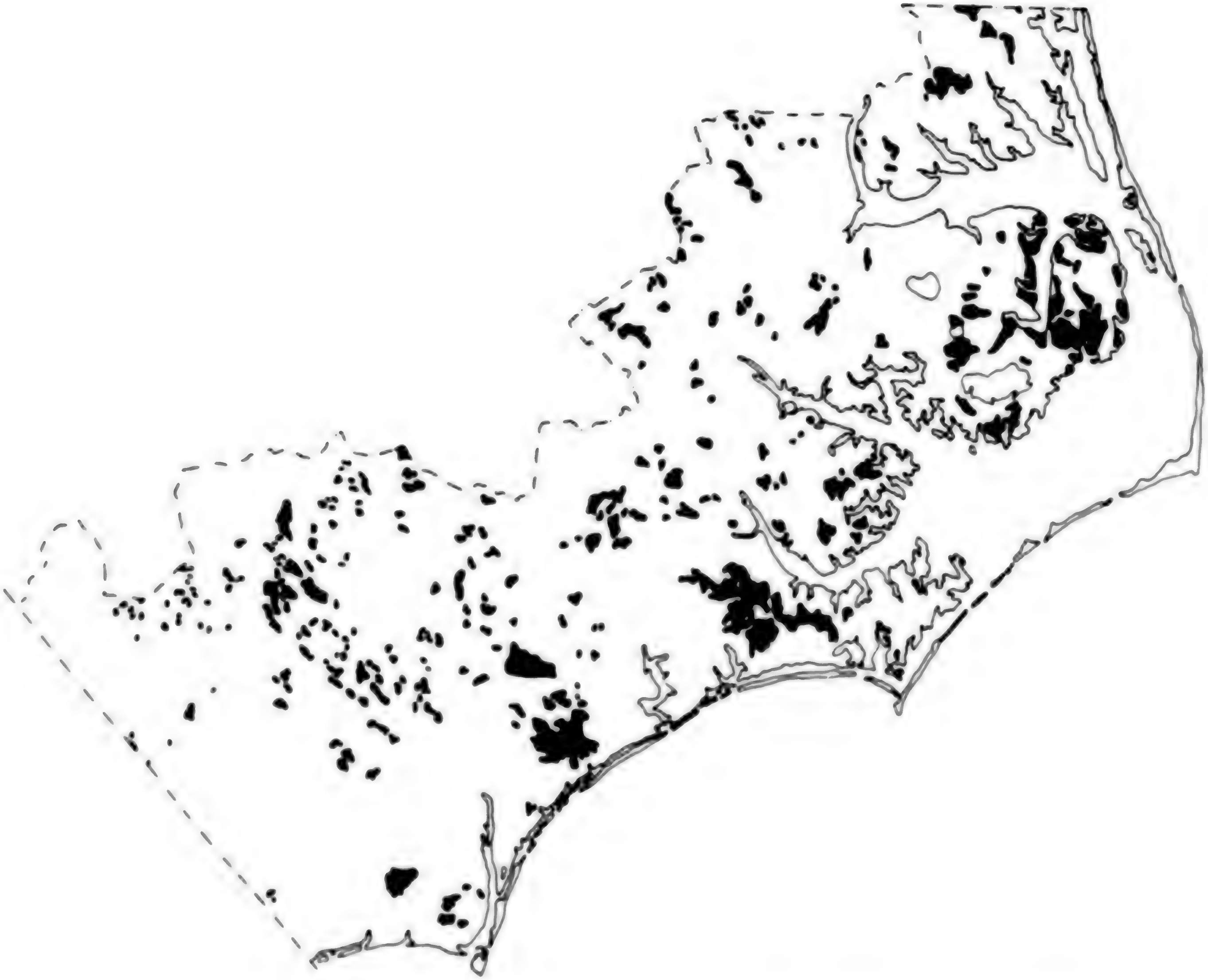

Figure 2. Extent of natural or slightly modified pocosin in 1980 (adapted from Richardson et al. 1981).

CHAPTER 2. CHARACTERISTICS OF NATURAL POCOSINS

DEFINITION AND CLASSIFICATION

The word pocosin is an Algonquin Indian term that means "swamp-on-a-hill" (Tooker 1899). In one of the earlier accounts Kerr (1867) defined pocosins as ". . . flatwoods with no natural drainage ways, different from swamps in that they are not alluvial, occurring on divides between rivers and sounds and frequently elevated above streams of which they were the source." Similarly, Harper (1907) characterized pocosins as ". . . extensive, flat, damp, sandy or peaty areas usually remote from large streams, supporting a scattered growth of pine and a very dense growth of shrubs, mostly evergreen, giving the whole a decided heath-like aspect. . . ." Later definitions by Wells (1928), Woodwell (1958), and Kologiski (1977) expanded the term pocosin by emphasizing community composition and physiognomy without regard to exact geographic position. By their definitions, pocosins consist of tangled masses of broadleaf evergreen or semi-evergreen shrubs and vines (titi, fetterbush, honeycup, bitter gallberry, and bamboo-briar) with emergent scattered pond pines and occasional bay trees (red bay, sweet bay, and loblolly bay). Such a description fails to emphasize that communities recognized as pocosins can vary considerably in stature of vegetation, density of trees, and species composition (Appendix A). In some instances all of the vegetation is stunted, producing a community dominated by shrubs (short pocosin, Figure 3). In other situations the understory vegetation is taller, and the frequency of pines increases until they attain dominance (tall pocosin, Figure 4). In still other instances, the broad-leaved evergreen red bay, sweetbay, and loblolly bay occur with sufficient frequency that these species become the canopy dominants. This variation in community composition has prompted the application of several community names that are all now considered to be roughly synonymous with the term pocosin. These include: bay, bay forest, bayhead, bayland, xeric shrub bog, and evergreen shrub bog (Wells 1928, 1942). Additionally, modifying terms such as "short" or "tall" are often used in conjunction with the word pocosin to describe the general stature of the vegetation (Snyder 1977, 1978). Using the system of wetlands classification developed by Cowardin et al. (1979), areas recognized as pocosins may fit into any one of the following categories: (1) palustrine, scrub/shrub, broad-leaved evergreen, titi-honeycup (*Cyrilla-Zenobia*) wetland; (2) palustrine, forested, needle-leaved evergreen pond pine (*Pinus serotina*) wetland; or (3) palustrine, forested, broad-leaved evergreen, sweet bay-red bay-loblolly bay (*Magnolia virginiana-Persea-Gordonia*) wetland. This classification helps emphasize the variability of pocosins and represents considerable refinement over an earlier system of wetland classification which simply placed pocosins in the category of bogs (Shaw and Fredine 1956).

PHYSIOGRAPHY AND GEOLOGIC ONTOGENY

Seventy percent of the nation's wetlands classified as pocosins are found in the lower and middle Coastal Plain of North Carolina (Figure 5) (Wilson 1962, Otte 1981). Within these relatively flat plains, pocosins are found in four distinct physiographic settings (Figure 6): blocked, poorly developed dendritic drainage basins (often designated upland flats or interstream divides); interior depressions of Carolina bays; swales in now-stabilized dune fields; and surrounding seeps, springs, and margins of slow-flowing streams in the Sandhills region (Christensen et al. 1981). The important unifying features of these areas are: (1) perched water tables usually due to impermeable clay layers at or near the mineral soil surface and (2) nutrient-poor water derived principally from rainfall or drainage through coarse sand aquifers. By far the most extensive pocosins occupy areas of blocked dendritic drainages while those found in Carolina bays cover far less area but are very numerous. Pocosins occupying either relict dune fields or seepage areas contribute only a small fraction of all pocosin acreage.

The ontogeny of pocosins that developed in blocked drainage basins is discussed by Otte (1981). About 10,000-12,000 years ago, sea level was 25 m (82 ft) below present, and the lower Coastal Plain was drained by poorly developed dendritic streams. At about this time, for reasons which are unclear, some of these streams became blocked by sandy sediments which in conjunction with impermeable clay layers beneath them led to open water systems supporting aquatic macrophytes. Anaerobic conditions in the water column supported the accumulation of organic matter (peat), eventually filling the open-water systems and replacing them with swamp forest (Figure 7). Since the shallow basins were lower than their surroundings, the swamp forests still received nutrients from upland runoff. Peat maintains a perched water table precluding its own oxidation so peat in

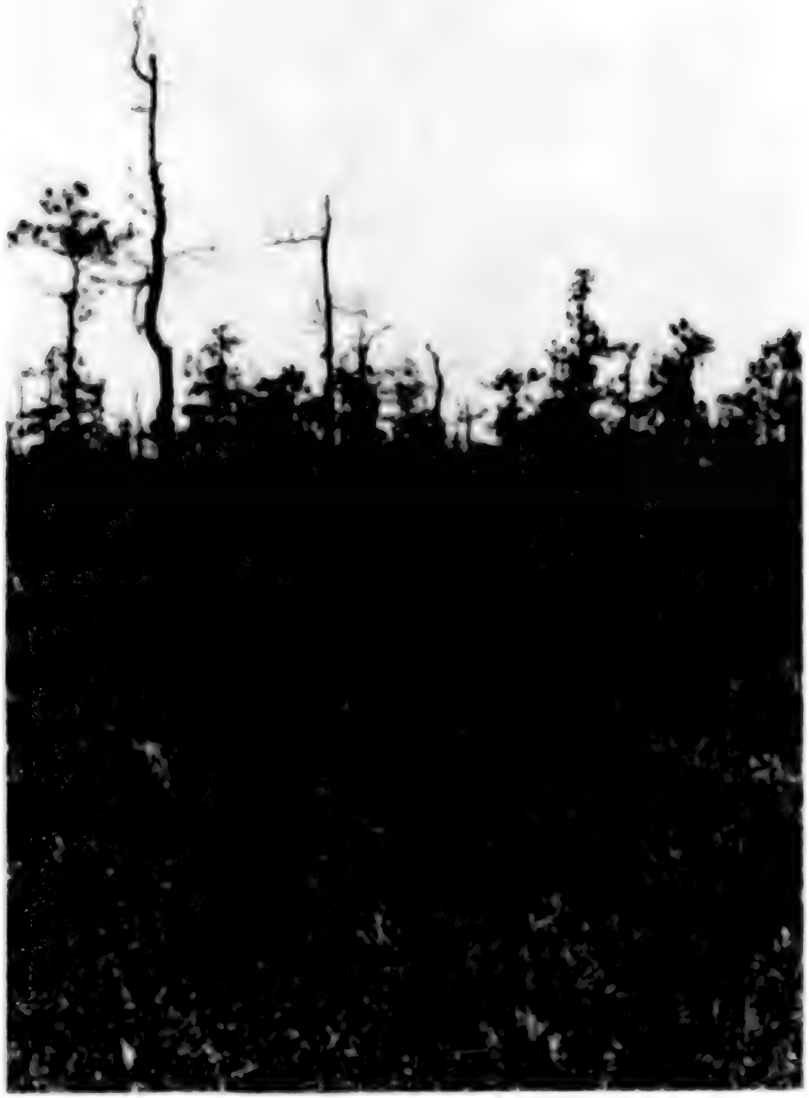

Figure 3. Short pocosin, Angola Bay, Pender County, North Carolina.

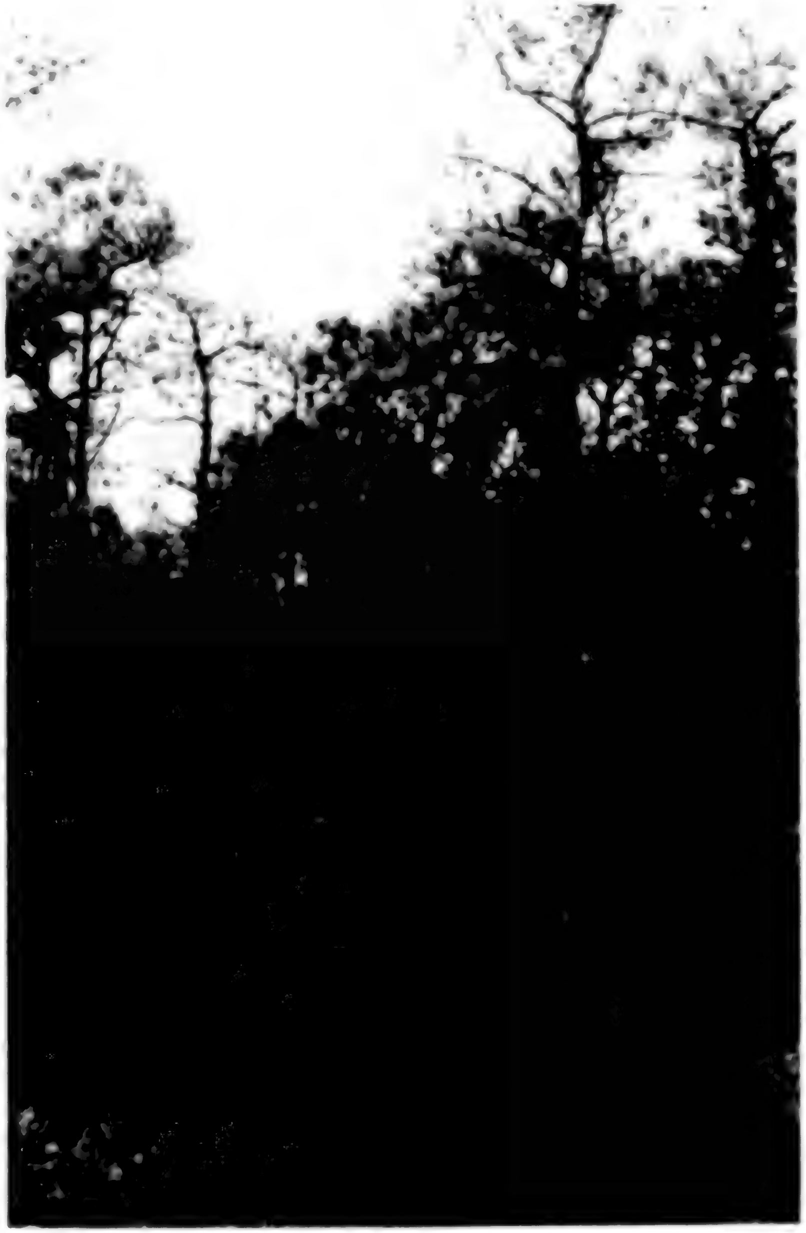

Figure 4. Tall pocosin, Dare County, North Carolina.

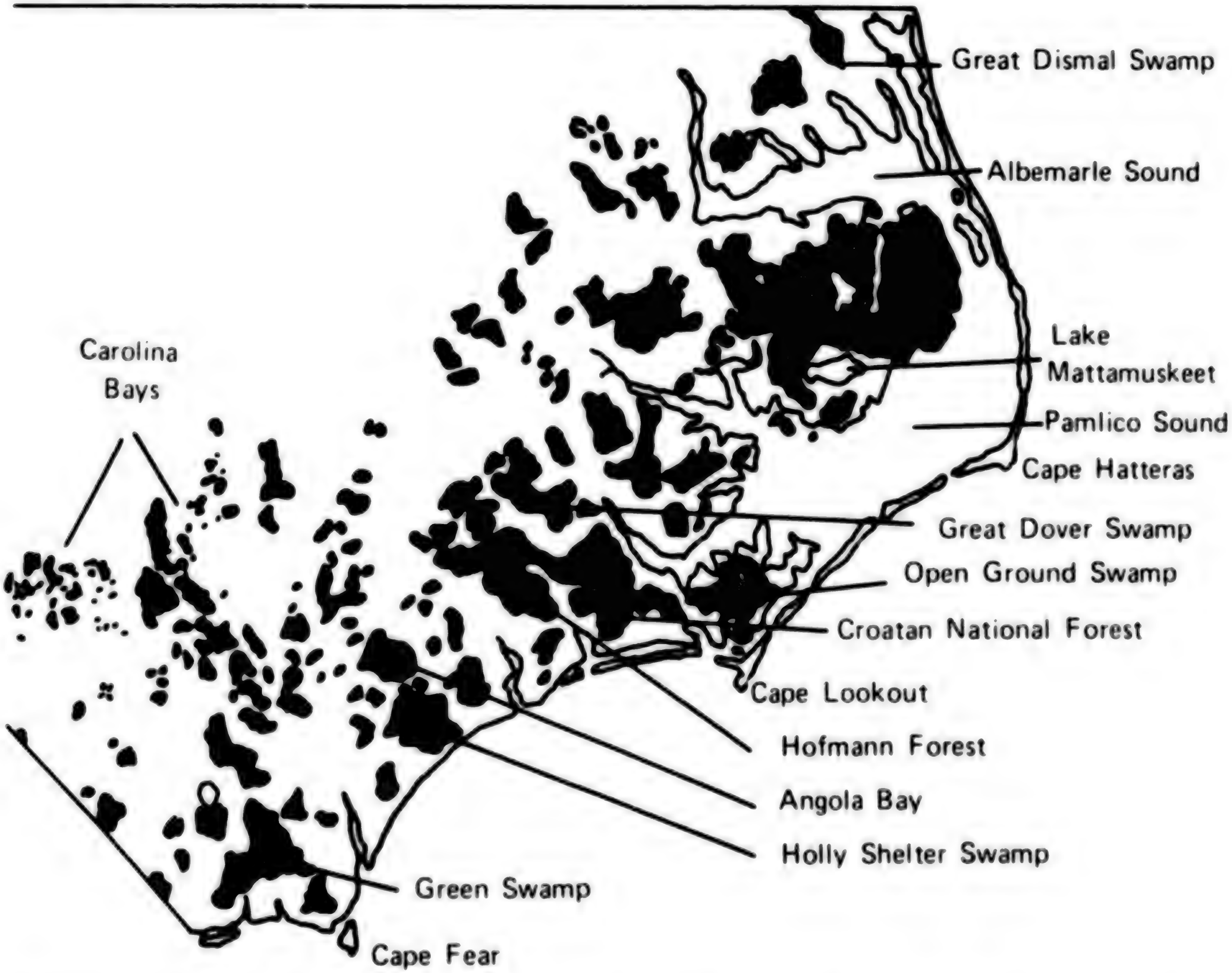

Figure 5. Location of North Carolina pocosins. This map also represents the approximate distribution of coastal plain organic soils (after Lilly 1981a).

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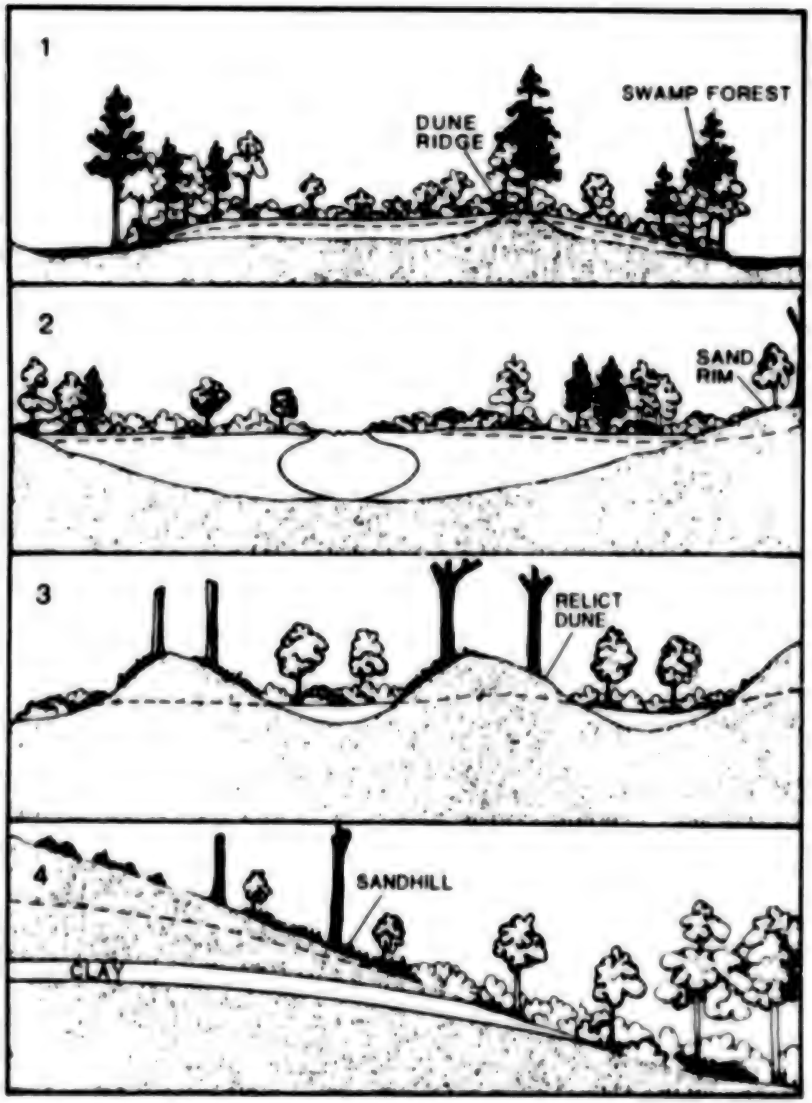

Figure 6. Physiographic location of pocosins: (1) upland flats, (2) Carolina bays, (3) relict dune fields, (4) seepage slopes.

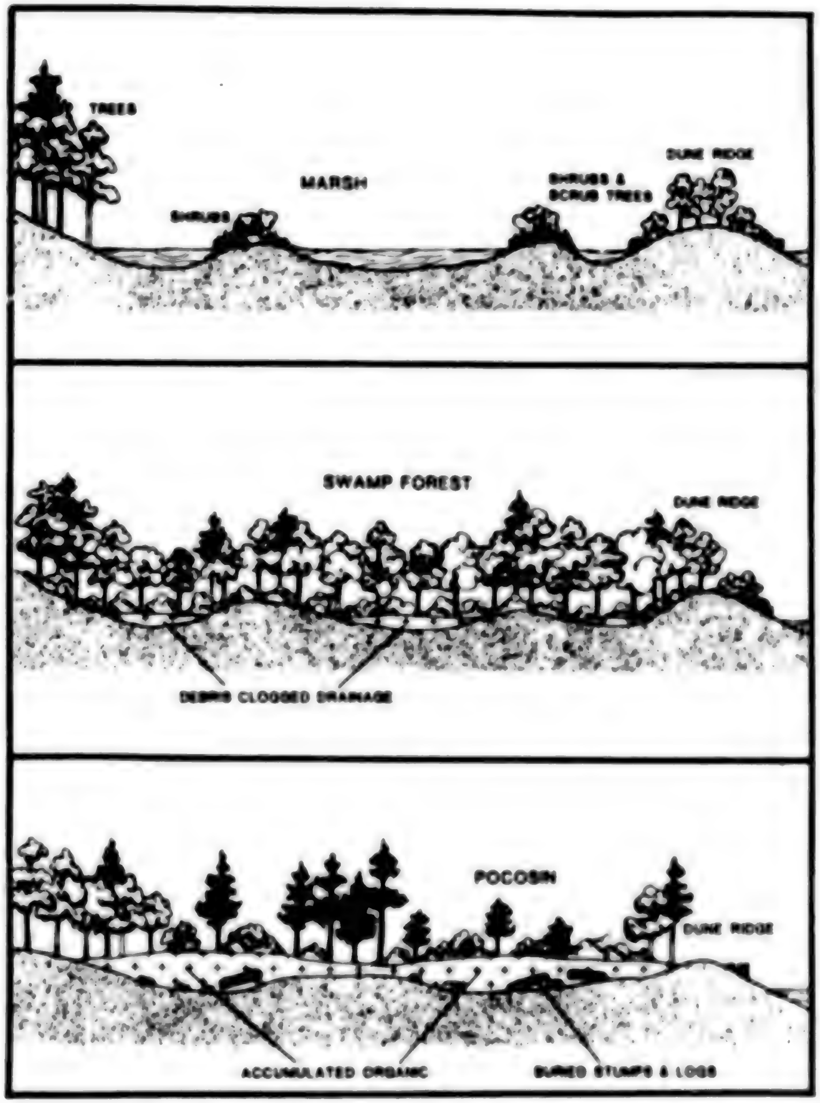

Figure 7. Pocosin development and organic soil accumulation in blocked drainage basins (adapted from U.S. Forest Service 1973a).

the swamp forests slowly accumulated, filling the old drainage channels and eventually spilling into adjacent flatlands. Once the peat surface was higher than surrounding areas, nutrient-rich upland runoff no longer entered, and swamp forest was replaced by pocosin. In most cases this latter transition occurred within the last several thousand years. Now these blocked drainage basins are true perched bogs (tertiary mires) with deepest peat and highest elevation near their centers. Vegetation near the centers is stunted (short pocosin) from deprivation of nutrients and becomes taller (tall pocosin) toward the periphery where the peat is shallower and growing conditions improve (Figure 8). Development of pocosins in Carolina bays follows a similar pattern (Otte 1981); however, not all bays contain pocosin vegetation. Those that do are underlain by nutrient-poor sand or peat with a deeper layer of impermeable clay in the deepest end of the bay. This soil structure produces natural ponds and initiates peat accumulation in the same manner and sequence as described for blocked drainages.

SOILS

A comprehensive discussion of pocosin soils is provided by Lilly (1981a). The soils of pocosins vary from dark surfaced mineral soils (usually Ultisols, Inceptisols, or Entisols in eastern North Carolina) to deep organic soils called Histosols (Figure 9). Organic soil material by definition must contain a mimimum of 20-30% organic matter depending on the amount of clay in the mineral fraction. For example, soil material with no clay can contain as little as 20% organic matter, but soil material with 60% clay must contain 30% or more organic matter to be so classified. In order for soil to be classified as a Histosol, organic soil material must be a certain thickness depending on such criteria as fiber content, bulk density, and periodic flooding. In most pocosins the organic soil material must be thicker than 40 cm (16 in) to be a Histosol. Soils with an organic soil material surface of 20-40 cm (8-16 in) are said to have histic epipedons, which literally means "mineral soils with organic topsoils."

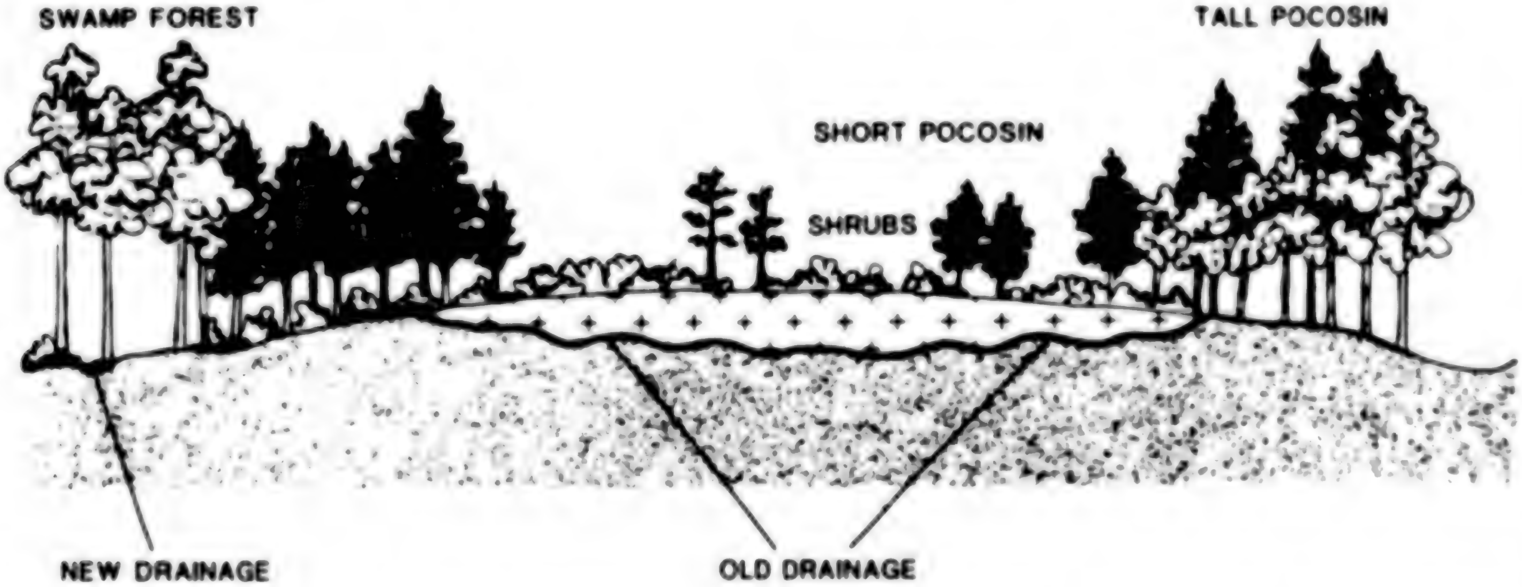

Figure 8. Transition from short to tall pocosin in relation to peat depth. Pocosin center is a topographic high (adapted from U.S. Forest Service 1973a).

Figure 9. Organic soil profile. Approximate depth 60 cm (24 in).

Essentially all Histosols in pocosins have sapric material (muck) containing less than 1/3 identifiable fibers in their subsoil layers. Sapric soils are more decomposed than soils with fibric material (peat). These soils belong to the suborder Saprist. The Histosols of pocosins are also in the Great Group Medisaprist which means they have no significant humilluvic horizons (material moved downward by leaching) and have a mean annual temperature above 8°C (46°F) with winter and summer means differing by at least 5°C (9°F).

Thick Histosols with sapric subsoil layers have higher bulk density, lower hydraulic conductivity, lower porosity, and retain more soil moisture than less decomposed Histosols. Sapric soils are sticky, plastic, impervious to water movement, and very acid. When undrained, they may be reddish due to reduced conditions. These soils are difficult to convert and farm because they do not allow water to drain through the profile and are often too plastic to support farm equipment.

The mineral soils buried by present-day organic soils were mostly deposited as recent marine sediments and vary from sand to clay. The type of material can change radically over a short distance, and its character has a strong influence on the physical and chemical properties of the entire soil profile. For example, organic matter-sand soils have less aluminum than organic matter-silt/clay soils and are unable to hold phosphorus effectively.

The Histosols of pocosins are classified into relatively few soil series because the organic soil materials are remarkably uniform in degree of decomposition and acidity. Many more mineral series are recognized because the texture of the mineral material varies greatly (Table 1).

NATURAL HYDROLOGY

Runoff water from natural pocosins, particularly large pocosins, is nutrient-poor (Daniel 1981, Richardson et al. 1981), colored (Heath 1975, Wilder et al. 1978), and has a pH of 3.5 to 4.1 (Barnes 1981, Gilliam and Skaggs 1981). In unmodified pocosins runoff is delivered to receiving areas, either rivers or estuarine shorelines, by sheet flow (Heath 1975, Daniel 1981) over broad stretches rather than from individual points such as streams or drainage ditches (Heath 1975, Pate and Jones 1980, Daniel 1981). Sheet flow occurs at the soil surface just under the accumulated litter (Heath 1975, Gilliam and Skaggs 1981) and follows small but relatively discrete channels. At some points on the

Table 1. Characteristics of Histosols and related mineral soils of pocosins (from Lilly 1981a).

Soil Series Name	Type and Thickness of Surface				Type of Organic Surface		Texture of Underlying Mineral		
	Organic 51 in +	Organic 16-51 in	Organic 8-16 in	Mineral or under 8 in Organic	Colloidal	Loamy (Mull)	Sandy	Loamy	Clayey
Dare	X				X		X		
Dorovan	X					X	X		
Pungo	X				X			X	I
Mattamuskeet		X			X		X		
Pamlico		X				X	X		
Belhaven		X			X			X	I
Scuppernong (1)		X			X			X	
Ponzer		X				X		X	
Conaby			X			X	X	I	
Wasda (2)			X		X			X	
Roper (3)			X		X			X	
Pettigrew			X		X				X
Portsmouth (2)				X				X	
Hyde (3)				X				X	
Weeksville (4)				X				X	
Cape Fear				X					X
Roanoke (5)				X					X
Argent (6)				X					X
Arapahoe (7)				X			I	X	
Fortescue (8)				X				X	

X = Primary characteristics; I = Secondary inclusions

1 = Silt layer in profile
2 = Fine-loamy; 18-34% clay, 15% or more sand coarser than vfs.
3 = Fine-silty; 18-34% clay, less than 15% sand coarser than vfs.
4 = Coarse-silty; less than 18% clay, less than 15% sand coarser than vfs.
5 = Not as wet as Cape Fear, fine sandy loam topsoil
6 = Similar to Roanoke. Fine sandy loam or silt loam topsoil
Higher pH in the lower B3 and C horizons
7 = Coarse-loamy; less than 18% clay, 15% or more sand coarser than vfs.
8 = Buried muck layer. Fine silty material over muck

Albemarle-Pamlico Peninsula, water once moved by sheet flow for distances of 16 km (10 mi) or more before reaching a river or estuary (Figure 10) (Heath 1975).

Because runoff from natural pocosins has a long residence time in soils of high organic content and low hydraulic conductivity, there is a characteristic delivery pattern to estuaries. In winter, when evapotranspiration is low, rates of runoff rise slowly, often peaking several days after the rain. Elevated rates may persist for a relatively long period before slowly tapering to normal flow (Heath 1975, Daniel 1981, Gilliam and Skaggs 1981). In summer, heavy rainfall is held by the soil and moves so slowly that most runoff is captured by plants and transpired to the atmosphere before it can reach receiving waters (Gilliam and Skaggs 1981). Due to extended interaction with large amounts of organic matter, water from pocosins is deficient in most cations and contains more phosphorus relative to that drained through mineral soil (Barnes 1981, Gilliam and Skaggs 1981).

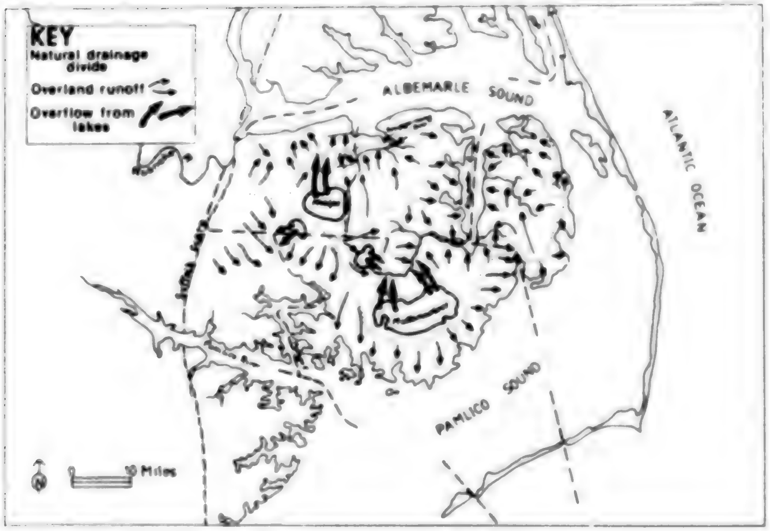

Figure 10. Sheet flow drainage patterns of the Albemarle-Pamlico Peninsula under natural conditions (redrawn from Heath 1975).

VEGETATION

The principal and most conspicuous component of the vegetation of any pocosin (Appendix A) is its dense layer of shrubs which can vary in height from 0.5 m to 4.0 m (1.5-13.0 ft). Although many shrubs are evergreen, a few are deciduous and others lose their leaves gradually through the winter. The shrub layer usually contains few species with the most important being titi, fetterbush, honeycup, bitter gallberry, and the woody vine bamboo-briar. In most pocosins scattered pond pines emerge above the shrubs. When the shrubs are short, the trees tend to be widely scattered on slightly elevated hummocks that are formed by an accumulation of litter and sphagnum (Sphagnum spp.) around the bases of living trees or stumps (Kologiski 1977). As the height of the shrub layer in a pocosin increases, the height and density of trees do also with the pond pines eventually becoming community dominants. In these areas loblolly bay, sweet bay, red bay, and red maple are often present on the shallower organic soils. In areas with shallow organic soils and frequent fire, the shrubs will be replaced by switch-cane producing a pocosin-related community known as pond pine savannah (Wendel et al. 1962, Wells and Whitford 1976). Pocosins succeeding to swamp forest usually have the tallest shrubs, mostly titi, sweet gallberry, male blueberry, and sweet pepperbush, and increased canopy diversity with the addition of black gum, Atlantic white cedar, and bald cypress. Canopy dominance also shifts in favor of broad-leaved evergreen bay trees and the resulting community is sometimes called a bay forest.

Very few species can adapt to the nutrient-deficient acid organic soils and long hydroperiods of pocosins (Appendices A and B). However, as Woodwell (1956) pointed out, the number of species is often greatest in pocosins with lowest productivity because openings remain which permit establishment of such herbaceous species as sphagnum, Virginia chain fern, sedges, trumpets, red pitcher plant, sundews, cottongrass, beakrush, bladderwort, yellow-eyed grass, hatpins, and broomsedge. In addition, open areas have shrubs like lambkill, leatherleaf, and huckleberry that are ordinarily shaded out by the growth of more robust species.

Physiological Characteristics of Pocosin Plants

Many shrubs in pocosins have leaves with a thickened cuticle and internal reinforcement with lignin which produces a rigid leathery texture (Christensen et al. 1981). Such sclerophyllous leaves are often associated with areas of drought, and their abundance in pocosins has caused considerable speculation. Suggestions of their adaptive value include reduction of damage from "physiological drought" (Schimper 1898), nutrient conservation (Monk 1966, 1971; Small 1972 a, b; Schlesinger and Chabot 1977), defense against herbivory, and increase in efficiency of photosynthesis (Schlesinger and Chabot 1977).

Another aspect of the leaves of some pocosin shrubs is their content of secondary chemicals. Shrubs like red bay, wax myrtle, and bitter gallberry are known to contain large quantities of aromatic compounds (Komarek 1974); thus, the leaf tissues of pocosin shrubs have comparatively high caloric values (Hough 1969). The adaptive significance of these compounds is uncertain, but they may have a role in defense against herbivores (Christensen et al. 1981).

The presence of abundant and diverse insectivorous plants, particularly where shrubs are low (Schnell 1982), is a characteristic feature of pocosins. Pitcher plants, sundews, butterworts, bladderworts, and Venus' fly-traps each have their own unique mechanism for capturing insects (Figures 11 and 12). The role of insects as alternative nutrient sources for these plants has long been suggested (Plummer 1963), and Christensen (1976) has demonstrated that insects can ameliorate deficiencies of nitrogen and phosphorus in these plants. A study by Weiss (1981) showed that nutrient removal promoted pitcher production and, presumably, insect trapping frequency in trumpets.

Fire

The aboveground biomass in pocosins varies considerably depending on time since last burning and productivity. In very nutrient-poor areas, aboveground biomass (minus the mass of tree boles) is approximately 1200 to 1880 g/m^2 (5.4-8.4 t/ac) (Christensen et al. 1981), whereas, in situations of greater nutrient availability, 3300 to 4700 g/m^2 (14.7-21.0 t/ac) is characteristic (Wendel et al. 1962). Even in areas of low productivity, the high flammability of shrubs and peat soils virtually assures that pocosins will burn at relatively frequent intervals (20-30 years). As a result, most species in pocosins are adapted to tolerate fire as exemplified by the shrubs which all sprout vigorously following burning. Christensen et al. (1981) reported that one pocosin, previously unburned for 25 years, regained nearly 25% of its biomass in the first growing season after fire. Pond pine provides another good example of fire adaptations by a pocosin species. Established trees are quite resistant to

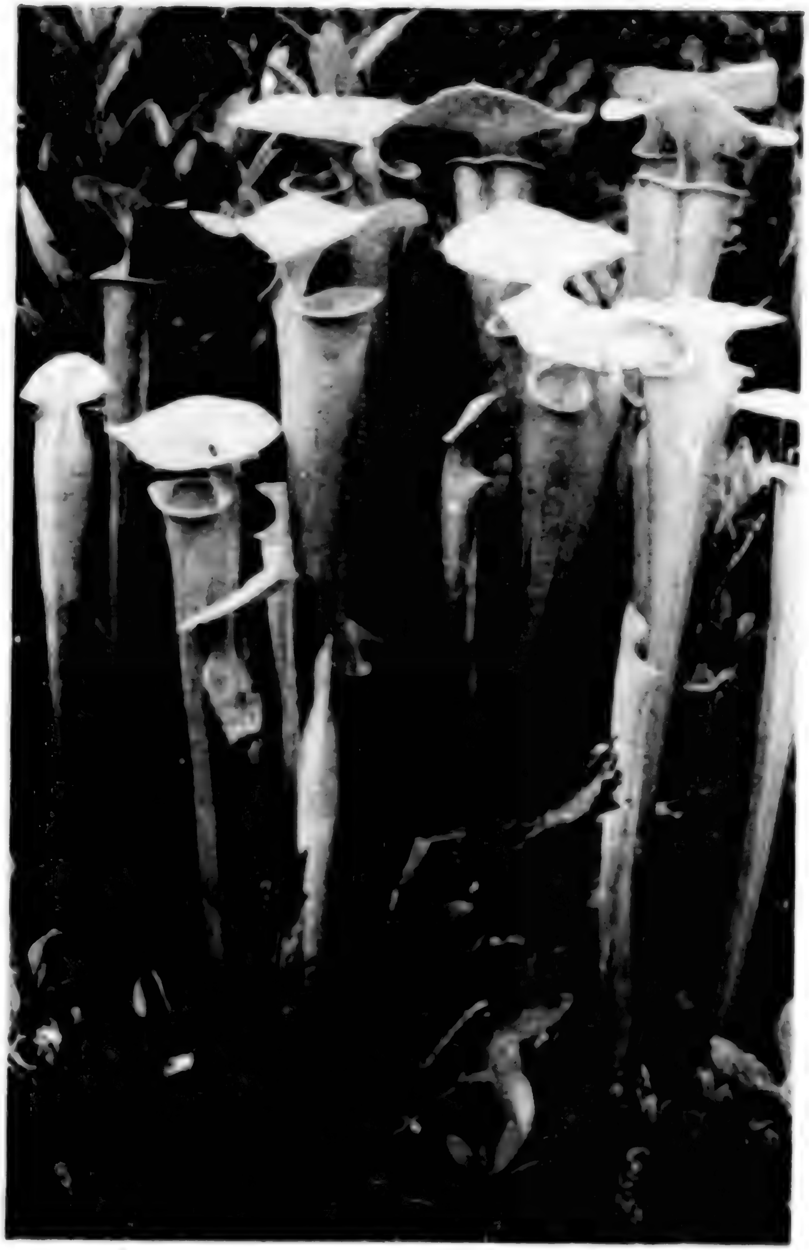

Figure 11. Trumpets (*Sarracenia flava*) in Croatan National Forest.

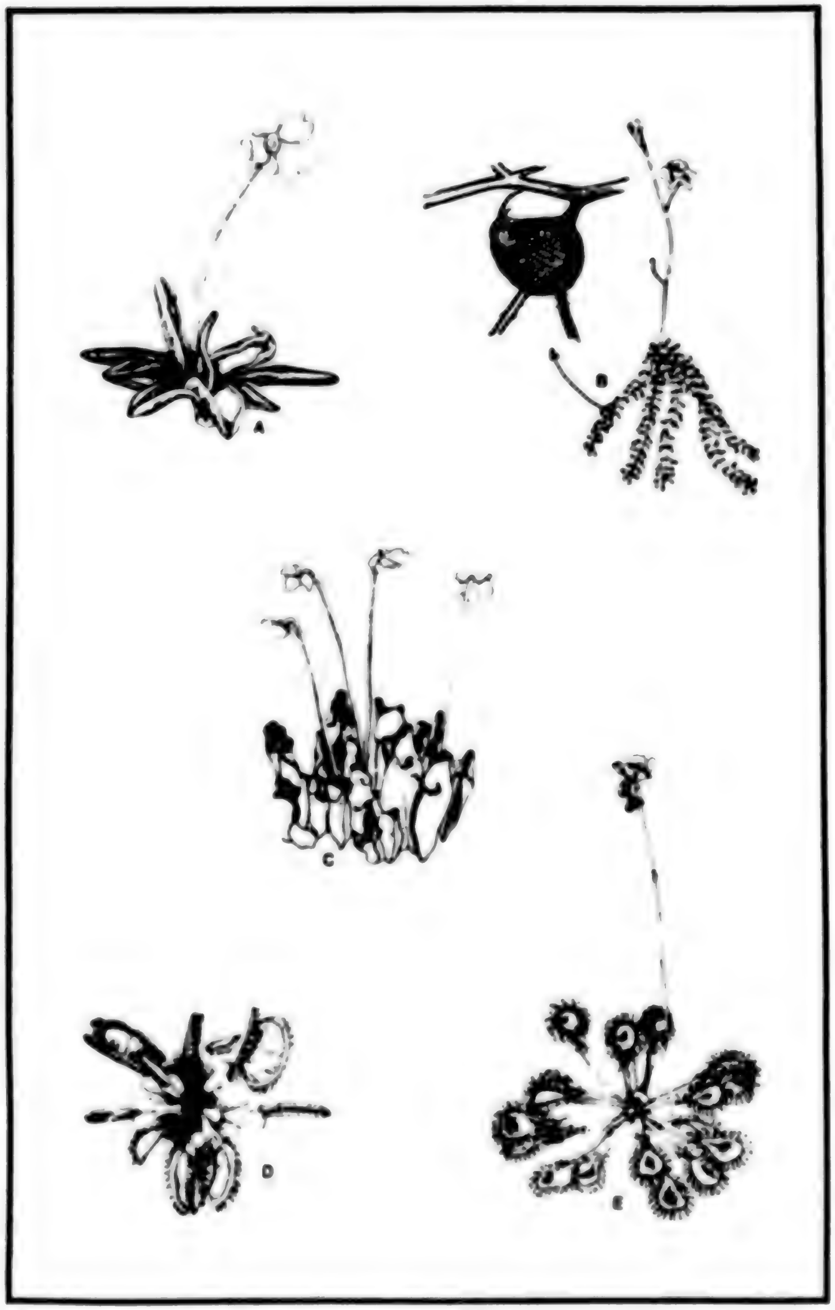

Figure 12. Types of insectivorous plants: (A) butterwort, (B) bladderwort, (C) pitcher plant, (D) Venus' flytrap, (E) sundew. Drawings not to scale.

fire, having the ability to sprout from either the roots or epicormic buds along the bole (Figure 13). This characteristic, uncommon in gymnosperms, produces the gnarled form of growth exhibited by many older trees. Trees also produce moderately serotinous cones which remain closed for two to ten years after seed maturation (Fowells 1968). Heat from a fire stimulates opening of cones and seed release at times when the probability of successful seedling establishment is highest (Woodwell 1958, Christensen et al. 1981). Because cones eventually open without fire, some seeds are released each year while a reservoir of seeds is retained on the tree.

Fire and vegetation patterns. The frequency and intensity of fire is an important factor in the physiogonomy and species composition of pocosins. Wells (1946) suggested the absence of pond pine or loblolly bay from some areas could be due to peat burns. He further proposed that deep peat burns would eliminate shallow-rooted honeycup allowing titi to attain dominance. Frequent shallow burns would favor honeycup because of its ability to sprout quickly and spread rapidly by rhizomes. Both Woodwell (1956) and Wells (1946) agreed that honeycup is indicative of recent disturbance, particularly fire, and that it is often associated with sweet pepperbush, lamb-kill, bitter gallberry, and leatherleaf. Woodwell suggested these species would be overtopped by titi and fetterbush within five years on favorable sites.

One important impact of fire is its effect on environmental heterogeneity (Christensen et al. 1981). Fires do not burn evenly. In some areas, fire may burn deeply into the peat, leaving depressions that are well below mean water table while other areas may be burned only lightly or spared completely (Figure 14). Thus, fire can cause vegetative heterogeneity in a formerly uniform community and plays an important role in maintaining plant species diversity.

Fire and succession. Penfound (1952) considered pocosins to be part of a successional sequence leading to swamp forests dominated by Atlantic white cedar. Wells (1928, 1942) and Kologiski (1977) described pocosins as successional or fire dis-climaxes. Descriptions by Ashe and Pinchot (1897) indicate that many present-day pocosins were Atlantic white cedar swamps prior to development. These observations seem to indicate that pocosins have been created from swamp forests by chronic fire and/or human disturbance. Although this may be true for some areas, most of the extensive raised bogs (short pocosins) have not changed significantly for several thousand years (Whitehead 1972,

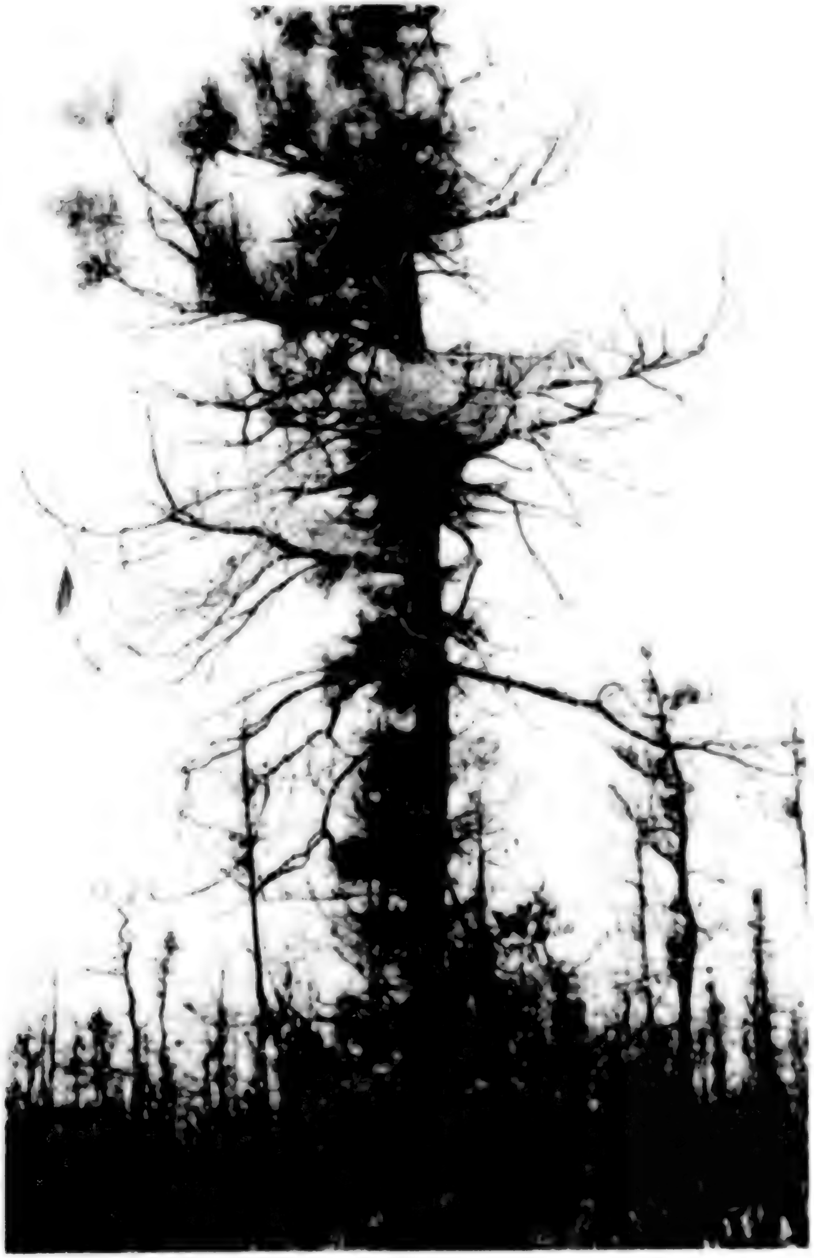

Figure 13. Pond pine sprouting from epicormic buds following fire.

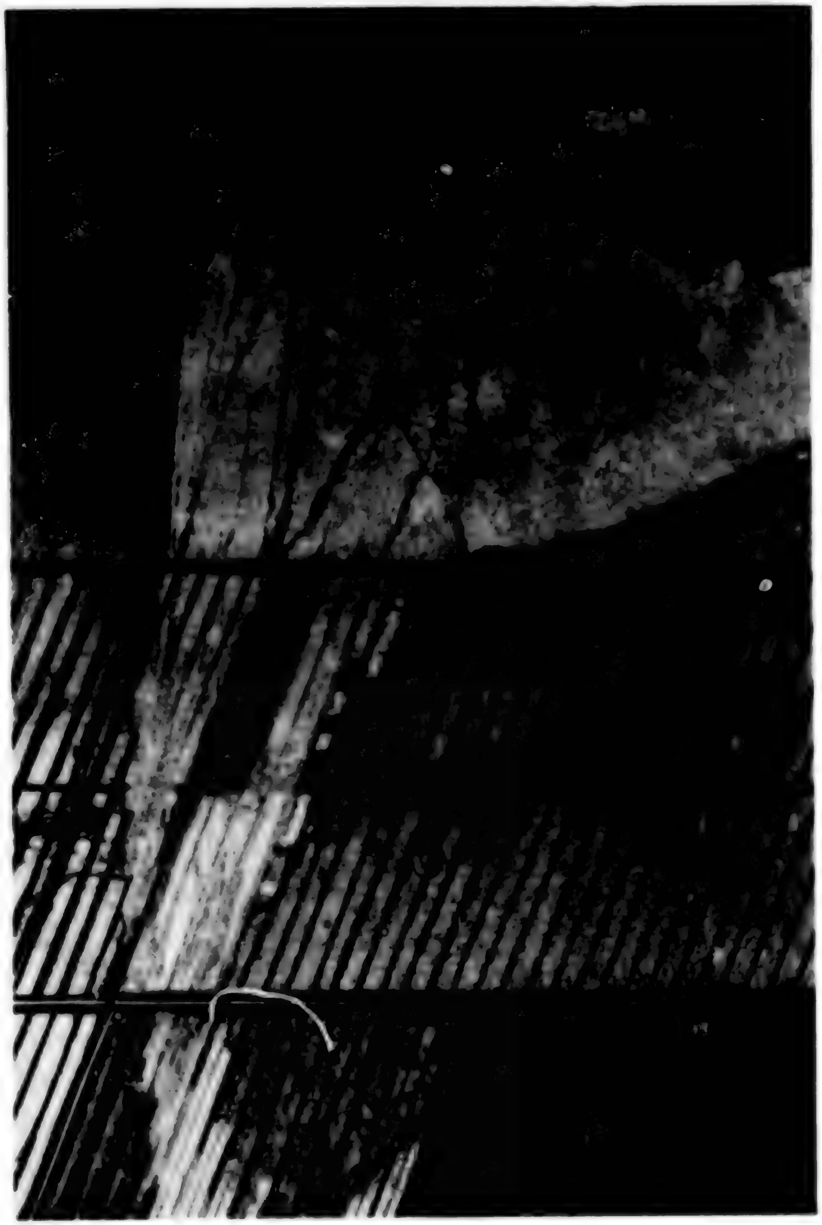

Figure 14. Aerial photograph of the fire pattern in a pocosin. The fire began in an area converted to agriculture (grid pattern in bottom half of photograph) and spread into adjacent natural pocosin. Note areas bypassed by fire seen as dark, approximately vertical lines in top half of figure.

Daniels et al. 1977, Otte 1981). Raised bogs lack typical swamp forest species like cypress, Atlantic white cedar, and black gum; and even in the absence of fire these nutrient-poor shrub-dominated pocosins remain quite species stable (Richardson et al. 1981). In transitional areas at the periphery of short pocosins the importance of fire in maintaining pocosin vegetation increases greatly. So, rather than creating pocosins de novo, fire and human disturbance have simply modified pocosin boundaries (Christensen et al. 1981).

VERTEBRATE FAUNA

Impenetrable vegetation, low standing crop (Christensen et al. 1981), and the absence of natural open water in pocosins leads to a relatively depauperate vertebrate fauna with few endemic species (David Lee, North Carolina Museum of Natural History, Raleigh, personal communication). In this regard pocosin wetlands are unusual because most wetlands are very productive of wildlife (Harris and Mulholland 1982). Recently, pocosins have become more important to wildlife despite their comparatively poor habitat qualities because extensive development of swamp forest and pocosin for row crop agriculture and silviculture has made it necessary for some species to use pocosins as habitat islands. These areas act as refuges for pocosin residents as well as those swamp forest species that can exist along edges between pocosin and adjacent ecosystems (Monschein 1981). Pocosin refuges are particularly important to black bear because of their strong avoidance of human activity. Representative lists of other vertebrates that inhabit pocosins, related freshwater wetlands, and water bodies are included as Appendices C, D, and E. There are several adaptations which seem to help animals survive in pocosins. Many animals are arboreal foragers, avoiding the often wet and unstable substrate. Examples are the golden mouse, rough green snake, and gray treefrog. Some animals such as swallows, fly catchers, and bats forage aerially. Species that are regular ground foragers such as bear and bobcat tend to be fairly large. In general, ground foragers are not common in pocosins.

Most true pocosin dwellers are either insectivorous (warblers, vireos, swallows, bats, treefrogs) or omnivorous (mice, bear). Few pocosin dwellers are strict carnivores because of the thick vegetation and low vertebrate biomass. Bobcats are the only true carnivores found in pocosins (Tom Monschein, North Carolina Wildlife Resources Commission, New Bern, personal communication), and some feel that even bobcats do not penetrate pocosins very deeply (Richard Lancia, School of Forestry, North Carolina State University, Raleigh, personal communication).

Pocosins that form habitat edge with other ecosystems are useful to many species of wildlife for both food and cover. Examples of animals that make good use of pocosin edge are deer, marsh rabbit, raccoon, opossum, dove, quail, waterfowl, timber rattlesnakes, copperheads, hog-nosed snakes, southeastern five-lined skinks, treefrogs, slimy salamanders, and Ranid frogs.

Pocosins are unusual wetlands because they normally have little open or running water within their boundaries. Due to the presence of peat, the few lakes and streams associated with pocosins often contain highly colored acid water. These characteristics tend to make fish a very minor component of pocosin fauna although streams associated with pocosins do produce some largemouth bass, sunfish, redfin pickerel, and several other species.

Wildlife species that utilize pocosin or pocosin edge will be mentioned in the chapter on species-specific management. Emphasis will be placed on endangered species and game species of importance to coastal plain wildlife managers.

ASSOCIATED ECOSYSTEMS

Several coastal plain biotic communities are characteristically associated with pocosins, either directly or through drainage water (Figure 15). Most share characteristics with pocosins and interact with them through biogeochemical cycles, water flow, and wildlife movement.

Freshwater Lakes

Shallow freshwater lakes are often associated with pocosins (Table 2) that have developed on upland flats or in Carolina bays. Many of these lakes have no natural inlets or outlets, but most now have outlet canals with floodgates to help control water level. The lakes vary greatly in size, shape, depth, water quality, and character of bottom sediments. Bottoms vary from sandy to mucky, and this is probably the major factor controlling water quality. Those with sandy bottoms have a pH near neutral while those with

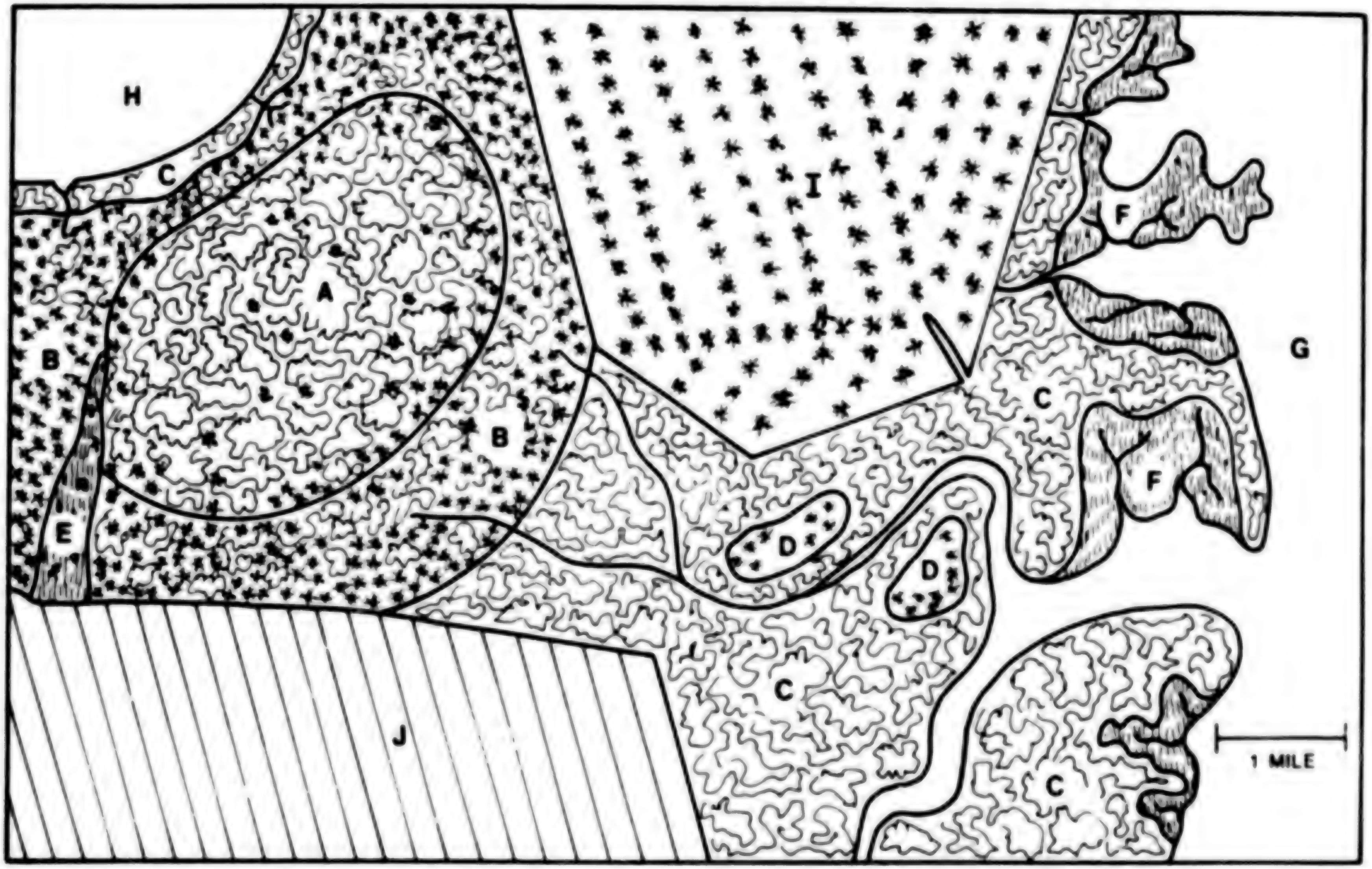

Figure 15. Diagram relating pocosins to adjacent ecosystems: (A) short pocosin, (B) tall pocosin, (C) gum-cypress swamp forest, (D) Atlantic white cedar swamp forest, (E) savannah, (F) marsh, (G) estuary, (H) lake, (I) pine plantation, (J) agricultural field.

Table 2. Major lakes associated with pocosin.

Name	Location (county)	Surface Area (hectares)	Surface Area (acres)
Lake Mattamuskeet	Hyde	20,200	49,900
Phelps Lake	Washington Tyrrell	6,600	16,300
Lake Waccamaw	Columbus	4,100	10,100
New Lake (Alligator Lake)	Hyde	1,900	4,700
Great Lake	Craven	1,200	3,000
Pungo Lake	Washington Hyde	1,100	2,700
Bay Tree Lake	Bladen	600	1,500
White Lake	Bladen	400	1,000
Lake Ellis-Simon	Craven	400	1,000
Long Lake	Carteret Craven	400	1,000
Catfish Lake	Craven	400	1,000
Singletary Lake	Bladen	200	500
Little Lake	Craven	200	500

muck bottoms have water that is acid and strongly colored (Heath 1975). Because the lakes are shallow, wave action easily stirs bottom sediments causing the larger lakes to remain turbid much of the time.

There is evidence that many of the lakes derive their water directly from precipitation rather than from overland runoff. For example, if Lake Phelps on the Albemarle-Pamlico Peninsula received overland runoff, the water would be highly colored because of its origin from pocosins south and west of the lake. However, the water has always been exceptionally free of color. Further, the estimated average annual evaporation of 91.4 cm (36 in) for the lake is about 38.1 cm (15 in) less than the region's average annual rainfall and if outflow is restricted, this difference alone should keep the lake filled (Heath 1975).

The development of most lakes and their surrounding peat soils can probably be explained by one of two theories. The first proposes that encroaching vegetation is slowly filling pre-existing lakes. This is most likely the pattern of development when both a lake and pocosin vegetation occupy the depression of a Carolina bay. The second theory proposes that fire burned deeply into existing peat with the resulting depression filling with water. It is likely that some of the lakes associated with pocosins on upland flats developed in this way. In fact, it is even stated in Indian legend that Lake Mattamuskeet was formed by a fire lasting 13 moons (Heath 1975).

Lakes are generally excellent habitat for waterfowl and some (Lake Mattamuskeet, Pungo Lake) are managed primarily for waterfowl as part of the U.S. Fish and Wildlife Service national wildlife refuge system. In addition, some lakes harbor rare and endemic fauna. Lake Waccamaw has the greatest number of rare and endemic species with three species of freshwater mussels (Waccamaw spike, *Elliptio waccamawensis*; Waccamaw mucket, *Lampsilis radiata*; Waccamaw lance, *Elliptio* sp.) and three species of freshwater fish (Waccamaw killifish, *Fundulus waccamensis*; Waccamaw silverside, *Menidia extensa*; and Waccamaw darter, *Etheostoma perlongum*). The Waccamaw killifish is also found in Lake Phelps (Cooper et al. 1977). The American alligator has been sighted in several lakes with a substantial population in Lake Ellis (Cooper et al. 1977).

Savannahs

Savannahs in North Carolina are associations of grasses and scattered longleaf pine trees. They invariably occur in conjunction with pocosins, developing on ridges or other high spots that are sufficiently elevated to prevent the accumulation of peat. The ridges or high spots may occur as part of broad upland flats, relict barrier island complexes, or rims of Carolina bays. The difference in elevation between savannahs and surrounding pocosins is often only a matter of centimeters. Since adjacent pocosin accepts little drainage, savannahs can be inundated by heavy rains and are classified as a type of palustrine wetland (Cowardin et al. 1979).

Savannahs are maintained by frequent fire, and their species are fire-adapted. Longleaf pine, the only tree, has excellent adaptations for fire, but also has periods of vulnerability. Trees are vulnerable during their first growing season, fire resistant for the next five to eight years in their "grass stage," and then vulnerable again for one to three years while they attain height as rapidly growing saplings (McIver 1981). With this growth pattern, annual fires would eventually eliminate longleaf pines from savannahs while a 10 to 30-year cycle would favor the development of a more closed woodland. Some intermediate pattern seems most likely, but the ideal fire regime is not known. For this reason, a variety of regimes is being used on savannahs managed by the North Carolina Nature Conservancy in the Green Swamp (McIver 1981).

Frequently burned savannahs support a great diversity of herbaceous plants. In one annually burned savannah in the Green Swamp, it was reported that 56 species of vascular plants were present in a single 1 m^2 (10.8 ft^2) plot, perhaps one of the highest such counts in the world (McIver 1981). With less frequent burning, competition from clump-forming grasses reduces diversity. As well as high diversity, savannahs support a number of rare species. These include Venus' fly-trap, sweet pitcher plant, yellow fringeless orchid, Wells' pyxiemoss, wireleaf dropseed, and others (Cooper et al. 1977). Perhaps the rarest animal in savannahs is the endangered red-cockaded woodpecker (Office of Endangered Species 1980). The extent of savannahs is extremely limited, and they are usually only a small portion of the pocosins with which they are associated. For example, savannahs make up only 93 ha (230 acres) of the 5605 ha (13,850 acre) Green Swamp Nature Preserve (McIver 1981).

Gum-Cypress Swamp Forests

Much of the Coastal Plain is relatively flat, and its rivers develop broad swampy floodplains dominated by one of two types of gum-cypress swamp forest. Rivers that drain Piedmont upland tend to have mineral-rich "brown water," and their swamp forests are dominated by tupelo gum and bald cypress growing on alluvial substrate. Rivers that drain coastal lowland tend to have "black water" that is low in silt but strongly colored by humic acids leached from the organic soils, and these "black water" streams are often associated with pocosins. Here, swamp forests dominated by bald cypress and black gum develop on organic substrate. Bald cypress tends to be most frequent near the streams with black gum dominant elsewhere. Swamp ash, red maple, and tupelo gum are common minor components but may become more important following disturbance, particularly logging. There is usually little undergrowth with only a few swamp herbs finding footholds on logs, stumps, and the swollen bases of gum trees; but this, too, can vary with a significant understory of sweet gallberry, bitter gallberry, fetterbush, and wax myrtle often developing in disturbed areas.

Atlantic White Cedar Forests

Atlantic white cedar is a common tree of coastal plain swamps or bogs, and in some places, it occurs in almost pure stands called Atlantic white cedar forests. These forests develop as dense even-aged stands in areas of stagnant water and highly acid peat overlying a sandy subsoil (Dean 1969). Since seedlings require full sunlight, Atlantic white cedar forests will only develop where openings are produced by clearcut logging or fire. Fire usually kills entire stands, and regeneration is dependent on the dense store of viable seeds in the upper layer of peat. If fire occurs during extremely dry periods when the upper peat layer can burn, it will eliminate the store of seeds, causing Atlantic white cedar forests to be replaced by either pocosin or gum-cypress swamp (Korstain 1924).

Atlantic white cedar is a tall, graceful tree with a straight bole and small crown. Its wood is light in color and weight, fragrant, and extremely durable. These qualities make the tree quite valuable for such things as buckets, fencing, boat planks, and home siding. For this reason, Atlantic white cedar forests have been cut repeatedly since colonial time, and there is evidence that their extent has diminished considerably.

Marshes

The tributaries and shores of North Carolina's principal estuaries are commonly fringed with marshes dominated by either smooth cordgrass (Spartina alterniflora), black needlerush (Juncus roemerianus), giant cordgrass (Spartina cynosuroides), sawgrass (Cladium jamaicense), or cat-tail (Typha spp.). Any of these species may occur in a given marsh, but dominance is generally determined by the salinity of adjacent estuarine waters. At salinities as great as 20 parts per thousand (ppt), smooth cordgrass and black needlerush are usually dominant. As salinity decreases, marshes become dominated by giant cordgrass and sawgrass. Fresh or very low salinity marshes are dominated by one of the four species of cat-tail.

Structurally, marshes grow on peat, silt, and clay soils, often underlain by a sandy substrate. A dendritic drainage pattern is typically present within the marsh. The vegetation is usually in a single layer though the dominant species can be 2-3 m (6.6-9.9 ft) tall. Primary production and standing crop are usually high.

Marshes of North Carolina have been shown to be important nursery areas for brown shrimp (*Penaeus aztecus*), white shrimp (*Penaeus setiferus*), and pink shrimp (*Penaeus duorarum*) (Birkhead 1977, Birkhead et al. 1977, Copeland and Hodson 1977, N.C. Div. of Mar. Fish. 1979) and commercially important finfish such as croaker, flounder, menhaden, and spot (Birkhead et al. 1977, Copeland and Hodson 1977, Weinstein 1979, Hodson et al. 1981). Freshwater systems (Roanoke River, Chowan River, Alligator River, Albemarle and Currituck Sounds) are important spawning/nursery areas for alewife and blueback herring (Johnson et al. 1977, Johnson et al. 1979). Other important anadromous species that may use similar areas are hickory shad, American shad, striped bass, Atlantic sturgeon, and shortnose sturgeon (Johnson et al. 1979).

Open Water Portions of Estuaries

The Atlantic Coast has an extensive system of sounds and estuaries. The following discussion of the Albemarle and Pamlico Sounds in North Carolina provides a general description of estuaries, although it cannot include the myriad of details by which individual estuaries differ.

Albemarle and Pamlico Sounds are partially enclosed by a series of long narrow barrier islands known as the Outer Banks. These sounds are connected to the ocean by five inlets which permit only limited mixing of fresh and salt water. While tidal input of salt water through the inlets is relatively constant, the input of fresh water from the land may vary considerably causing salinity to change with seasonal and sporadic patterns of freshwater flow. Salinities tend to be highest during the months of November and December (about 3.5 ppt in the vicinity of Alligator River) and lowest (about 1.8 ppt in the vicinity of Alligator River) during the months of March, April, and May. Highest salinities are recorded in the Pamlico Sound (20 ppt) with values decreasing as one moves up the Pamlico and Neuse River estuaries. By comparison, Albemarle Sound is quite fresh because of its greater flow rate and distance from inlets (Bowden and Hobbie 1977).

The presence of the Outer Banks greatly dampens the influence of lunar tides. Tides that average about 1.4 m (4.5 ft) in the Atlantic Ocean off Cape Hatteras are reduced to less than 0.2 m (0.5 ft) in the interior of the sounds except when increased by wind or storms.

Pamlico River Estuary. The Pamlico River Estuary extends 61 km (38 mi) with a greatest width of 7.25 km (4.5 mi). It is shallow with an average depth of about 3.4 m (11 ft). The drainage basin consists of 7975 km^2 (3080 mi^2) of the Tar River and several smaller streams that drain an additional 3100 km^2 (1200 mi^2). Salinity ranges between 0.5 and 20 ppt. Changes in salinity are closely related to the amount of inflowing fresh water but are also influenced by wind speed, wind direction, and the Coriolis force. In general, salinities are lower along the south shore as a result of these factors (Hobbie 1970a). Water temperatures range from near freezing to 34°C (93°F), over an annual cycle, but temperatures above 32°C (89°F) are unusual.

With the Pamlico River's large surface and shallow water, its mixing by wind usually maintains adequate aeration. However, the river occasionally stratifies in the summer or fall during periods of calm weather when a combination of warm temperatures and organically rich water and bottom sediments can cause depletion of dissolved oxygen below the halocline (Davis et al. 1978). This results in large kills of benthic animals such as clams, other bivalves, snails, and marine worms. Annual recruitment reestablishes these communities (Tenore 1972).

Investigations of nutrient concentrations and cycling dynamics for the Pamlico River Estuary have been conducted by Hobbie (1970b, 1974), Copeland and Hobbie (1972), and most recently by Kuenzler et al. (1979). Hobbie (1970b) found the Pamlico River naturally rich in phosphate; concentrations in the Tar River surpass the upper limits for unpolluted coastal waters, and even higher levels have been recorded in the Pamlico Estuary near the Texasgulf phosphate plant at Aurora (Hobbie 1970b). Nitrogen:phosphorus ratios of 7:1 were reported by Jaworski (1979) and a ratio of 3:1 was found by Kuenzler et al. (1979) in the vicinity of the Texasgulf plant. This indicates that phosphorus in the Pamlico River Estuary far exceeds that needed for algal growth and that nitrogen is likely to be a limiting nutrient. According to Kuenzler et al. (1979), nitrogen inputs to the river are only sufficient to supply about 5% of the annual uptake by phytoplankton. Of this, only about 2% is contributed by the watershed, with the remaining 3% transported into the estuary by advection and dispersion from the Pamlico Sound. Thus, it is primarily nitrogen recycling within the estuary that determines nutrient availability and phytoplankton productivity. The Pamlico River experiences cold season blooms of the dinoflagellate *Heterocapsa triquetra* during January through March. The blooms are usually restricted to the middle and upper portions of the river and are associated with high inorganic nitrogen concentrations.

Chowan River Estuary and Albemarle Sound. The Chowan River and Albemarle Sound differ considerably from the Pamlico system. Besides greater area, a larger drainage basin, and lower salinity, there are considerable differences in nutrient dynamics and algal growth. This is partly reflected in summer algal blooms that occur in the lower Chowan River. These blooms are stimulated by a combination of low flow rates allowing longer residence times for both nutrients and algae, high nutrient levels, and warm temperatures. The blooms involve five species of blue-green algae: three are species of *Anabaena*, one *Microcystis*, and one *Aphanizomenon* (Witherspoon et al. 1979). Studies of nutrient kinetics by Stanley and Hobbie (1977) indicate that nitrogen and phosphorus concentrations are always sufficient to support algal growth. Despite adequate nutrients, algal blooms seldom occur in the Albemarle Sound. Here, algal growth in winter is likely limited by a combination of temperature, light, and washout due to high flow rates. In summer, turbidity which reduces light levels is probably the main limiting factor, but high flow rates can be important at certain times (Bowden and Hobbie 1977).

CHAPTER 3. HISTORY, EXTENT, AND TECHNIQUES OF POCOSIN DEVELOPMENT

HISTORY OF DEVELOPMENT

Early Accounts and Descriptions

Although early descriptions are usually incomplete, they are sufficient to show a long history of pocosin recognition and use. The first descriptions indicate that pocosins much like today's were present when European explorers first ventured into the Carolina coastal plain. In Lawson's 1709 New Voyage to Carolina (Lawson 1952), he wrote, "As we row'd up the river, we found the land towards the mouth and for about 16 miles up it scarce anything but swamp and percoarson (pocosin) . . ." Since both pocosin and swamp are mentioned in the same passage, it is evident that even early explorers recognized the difference between pocosin and swamp forest. Perhaps the earliest description of the vegetation of pocosins was given by Brickell in 1737 when he stated that they are " . . . very wet and low lands so full of cane and underwood, that there is no passing through them."

Drainage for Agriculture in the 18th and 19th Centuries

Some early accounts fail to distinguish between swamp and pocosin, particularly when describing early attempts to drain wetlands for either agriculture or forestry. From geographic locations, however, it is evident that some early projects involved the drainage of both swamp forest and pocosin. One area was the Great Dismal Swamp. It was realized quite early that the Swamp was highest at its center, and it was asserted that a canal leading from the center would easily drain it making land available for agriculture. In 1764, the Dismal Swamp Land Company with George Washington as one of its members was chartered by the Virginia Assembly. The company succeeded in digging a canal from Lake Drummond to facilitate logging, but plans for farming failed (Lilly 1981b). Elsewhere settlements were being established in shallow wetland areas that must have required some drainage. Two were Fort Landing, about 1700, and Gum Neck, about 1750, both in Tyrrell County on the Albemarle-Pamlico Peninsula (Heath 1975).

By the early 1800's, several drainage ventures had become quite successful; like the Dismal Swamp project, they involved the drainage of both wetlands and lakes. In the area around Lake Mattamuskeet, an estimated 13,000 ha (32,000 ac) were in cultivation by 1839 (Ruffin 1861). Due to serious flooding in 1836, the state provided money to dig a canal from the lake to Wysocking Bay, lowering the water 1.1 m (3.5 ft) (Lilly 1981b) and reducing the flood threat. In the northern part of the Albemarle-Pamlico Peninsula, a canal was dug from Lake Phelps to the Scuppernong River. Because of differences in elevation, this made water power available for a sawmill and other machinery as well as providing a way to drain and flood rice fields. Rice culture was abandoned after a few years, but considerable income was still derived from cypress logging (Lilly 1981b). By 1839, an estimated 2,000 ha (5,000 ac) were being farmed by several proprietors with the major landholders being Josiah Collins on Somerset Place plantation and the Pettigrew family on neighboring Bonarva (Ruffin 1861).

During the middle 1800's, a major investor in drainage projects was the North Carolina State Literary Fund which derived money from the sale of swamp land. It set aside $200,000 for development and spent much of this digging drainage canals at Lake Mattamuskeet, Alligator Lake, and Pungo Lake on the Albemarle-Pamlico Peninsula. Additionally, in 1855 a canal was dug to the center of Open Ground Swamp in Carteret County. These projects failed to generate any successful sales and efforts by the state to develop swamp land for agriculture ended in 1860 (Lilly 1981b).

Logging Virgin Forests

By the 1880's emphasis was shifting from agriculture to forestry, particularly in areas with deep organic soil. On the Albemarle-Pamlico Peninsula, the Roper Lumber Company owned an estimated 243,000 ha (600,000 ac) and had cutting rights to 81,000 ha (200,000 ac) more. In the same region, the Richmond Cedar Works was estimated to have cut between 400,000 and 800,000 ha (1-2 million ac) (Hanlon 1970). Both made extensive use of logging railroads and other mechanical aids to help transport the harvest. In other pocosins a similar pattern continued into the early part of the 1900's.

The logging history of the Green Swamp in Brunswick and Columbus Counties was discussed by Kologiski (1977), and he provides a good description of the changes there. The first recorded use of the Green Swamp was selective logging of large cypress trees for shingles in 1861. A swamp timber survey in 1870 described cypress and gum as the overwhelming dominants, with white cedar and pine extremely important. After 1870, a large part of the swamp changed ownership several times until it was finally purchased by the Waccamaw Lumber Company in 1906. Despite some selective cutting and natural fires, much of the swamp was still dominated by cypress, gum, white cedar, and pine at the turn of the century. During ownership by the Waccamaw Lumber Company, most of the forested parts of the swamp were cut using railroads and steam skidders to transport the harvest. No roads were built so most of the swamp remained fairly inaccessible. Extensive areas of slash and brush left by the cutting provided fuel for wild fires and encouraged establishment of fire-tolerant pocosin species like honeycup, titi, and pond pine. Logging, therefore, may have increased the extent of pocosin and decreased swamp forest.

Establishing Pine Plantations

At the same time that virgin forests were being depleted in the East, the demand for paper was increasing. Since cutover forest land was relatively cheap, paper companies began purchasing large tracts from lumber companies and converting them to pine plantation (Lilly 1981b). In most areas natural drainage was not adequate for pine production, so paper companies began constructing extensive systems of ditches and canals. Governments were involved in similar development. In 1934 the North Carolina Forest Foundation established Hofmann Forest (31,600 ha; 78,000 ac); and in 1936, the federal government made the initial acquisition of 61,600 ha (152,000 ac) in the Croatan National Forest. As a result, by the 1960's most pocosins were crisscrossed with networks of drainage ditches. The only areas remaining unmodified had such nutrient deficient soils and poor drainage that loblolly pines simply would not grow.

A Shift Back to Agriculture

Despite some unsuccessful earlier attempts, the better technology and improved commodity prices of the early 1970's were enough to stimulate new interest in large scale development of pocosins for agriculture. Activity centered on the Albemarle-Pamlico Peninsula where three corporate groups acquired over 160,000 ha (400,000 ac) (Carter 1975). Here and elsewhere, natural pocosin, cutover pine plantation, and swamp forest were all rapidly developed for production of row crops.

A New Use for Deep Organic Soils

Despite successful conversion of many pocosins, those with extremely deep organic soil have not proven amenable to either forestry or agriculture. Their low nutrient availability and poor internal drainage make them unsuited for loblolly pines, and even though farming is possible, removal of undecayed logs and stumps from the soil profile is a never-ending problem (Heath 1975). However, when oil prices began rising in the middle 1970's, people began looking at deep peat pocosins as potentially valuable energy resources. Peat mining technology and markets are presently being developed and several corporations have applied for mining permits. It has also been proposed that the underlying mineral soil of many areas will be suitable for agriculture once the peat is removed. Experiments with small test plots by First Colony Farms have shown that crop yields in reclaimed peat-mining areas compare favorably with some of North Carolina's best farmland (Taylor 1981).

PRESENT OWNERSHIP AND EXTENT OF RECENT LAND CONVERSION

Present Ownership

Proportions by user group. Pocosins are predominately owned by either timber companies, corporate farms, or state or federal agencies. The greatest portion, 44%, is owned by major timber companies; and since much of the government-owned 18% is federal or state forest, about 60% of all pocosin is owned by timber producing interests. The 12% belonging to private landowners is either cropland, forest land, or natural vegetation. Large corporate farms own 21%, representing the only major shift of ownership in many years. Increase in corporate farm ownership resulted from the transfer of nearly 200,000 ha (500,000 ac) of corporate forestland to large-scale agriculture in the early 1970's (Richardson et al. 1981). Less than 5% of all pocosin habitat is protected from development (Richardson et al. 1981).

Great Dismal Swamp. Although only a small portion of the Great Dismal Swamp may be classified as pocosin, it has been included here because of its proximity to other large pocosins. Perhaps as much as 80% of the swamp has been developed for either timber production or agriculture. In 1973, Union Camp Corporation gave 20,000 ha (49,000 ac) to the Department of the Interior for the Great Dismal Swamp

National Wildlife Refuge. Since then the refuge has been increased to 39,300 ha (97,000 ac) with plans for eventual expansion to 47,000 ha (116,400 ac), or about half the swamp as it now exists (Craig 1973, Cahill 1974). About 5,800 ha (14,300 ac) of the swamp is owned by the State of North Carolina.

Albemarle-Pamlico Peninsula. Most pocosin land in this area is privately owned with the greatest portion belonging to several corporate farms. First Colony Farms, the principal owner, had about 152,000 ha (376,000 ac) in the middle 1970's, but has since sold several tracts (Lilly 1981b). Their ownership includes much of mainland Dare County, with large holdings in Tyrrell and Washington Counties, and some in Hyde County. Pocosin in public ownership includes 16,200 ha (40,000 ac) used as an Air Force bombing range and 5,000 ha (12,000 ac) managed as Pungo National Wildlife Refuge.

Pamlico-Neuse Peninsula. The major pocosins in this area are Gum Swamp, Bay City Pocosin, Light Ground Pocosin, and Big Pocosin which together cover over 20,000 ha (50,000 ac), all in private ownership. Much of the land not owned by paper companies is being cleared for agriculture (Lilly 1981b).

Open Ground Swamp. In 1929, Dachnowski-Stokes and Wells estimated that Open Ground Swamp covered 20,000 ha (50,000 ac). About 16,000 ha (40,000 ac) is now being developed for agriculture by a corporate group called Open Ground Farms. Most of the remainder belongs to paper companies (Lilly 1981b).

Croatan National Forest and Hofmann Forest. Most of the pocosin in these areas is government-owned and primarily managed for timber production. Croatan National Forest is 61,700 ha (152,000 ac) while Hofmann Forest is 32,000 ha (78,000 ac).

Holly Shelter and Angola Bay. In 1827, Holly Shelter consisted of 23,600 ha (58,240 ac) in state ownership (Kerr 1867). Presently, 19,600 ha (48,470 ac) is managed as Holly Shelter Wildlife Management Area by the North Carolina Wildlife Resources Commission (Powell 1968). In 1827 Angola Bay was surveyed at 20,000 ha (50,000 ac) in state ownership; however, the Wildlife Resources Commission was assigned only 8,500 ha (21,000 ac) in 1942 (Pomeroy and Yoho 1964). Most of the remainder is now owned by paper companies.

Green Swamp. Estimated to cover about 36,000 ha (90,000 ac) (Powell 1968), the Green Swamp is mostly owned by paper companies. In 1977, 5,600 ha (13,850 ac) was given to The Nature Conservancy by Federal Paper Board Company and is now managed as the Green Swamp Nature Preserve.

Extent of Recent Land Conversion

Although general trends of pocosin conversion are obvious, it is extremely difficult to determine exact changes because most older maps fail to accurately delineate vegetation boundaries. However, county maps of the distribution of wetland types, including pocosin, were contained in a 1962 survey of North Carolina wetlands (Wilson 1962) and provide a basis for comparison with modern Landsat imagery. In this way, Richardson et al. (1981) determined that the 907,960 ha (2,243,000 ac) of natural or slightly altered pocosin mapped in 1962 had shrunk to 608,260 ha (1,503,000 ac) in 1979. This means that nearly 33% of the pocosin present in 1962 had been totally converted to either agriculture or silviculture. In addition, pocosin partly altered through draining or clearing, or planned for development by owners, accounted for another 327,000 ha (808,000 ac). With this included, the extent of natural pocosin in 1979 had shrunk to 281,300 ha (695,000 ac), only 31% of that mapped by Wilson 17 years earlier (Figures 1 and 2).

Recent changes in Tyrrell County, North Carolina. Land conversion in Tyrrell County on the Albemarle-Pamlico Peninsula provides a good example of the extensive changes in that region during the last eight years (Figures 16 and 17). Conversion has been to agriculture from what was once cutover pine plantation, natural pocosin, or swamp forest. It is estimated that 11,000 ha (27,160 ac) of formerly forested land has been converted to agriculture in this county since 1974 (McDonald and Ash 1981).

TECHNIQUES OF LAND CONVERSION

Agriculture and forestry use similar land conversion techniques. Both begin with establishment of canal systems that discharge into creeks, rivers, marshes, or swamp forests. Lateral canals 3-6.5 m (10-15 ft) deep and wide are spaced about 0.8 km (0.5 mi) apart (Lilly 1981a) and the spoil is usually smoothed for a roadway. In some instances canals dug many years earlier for timbering can be used for

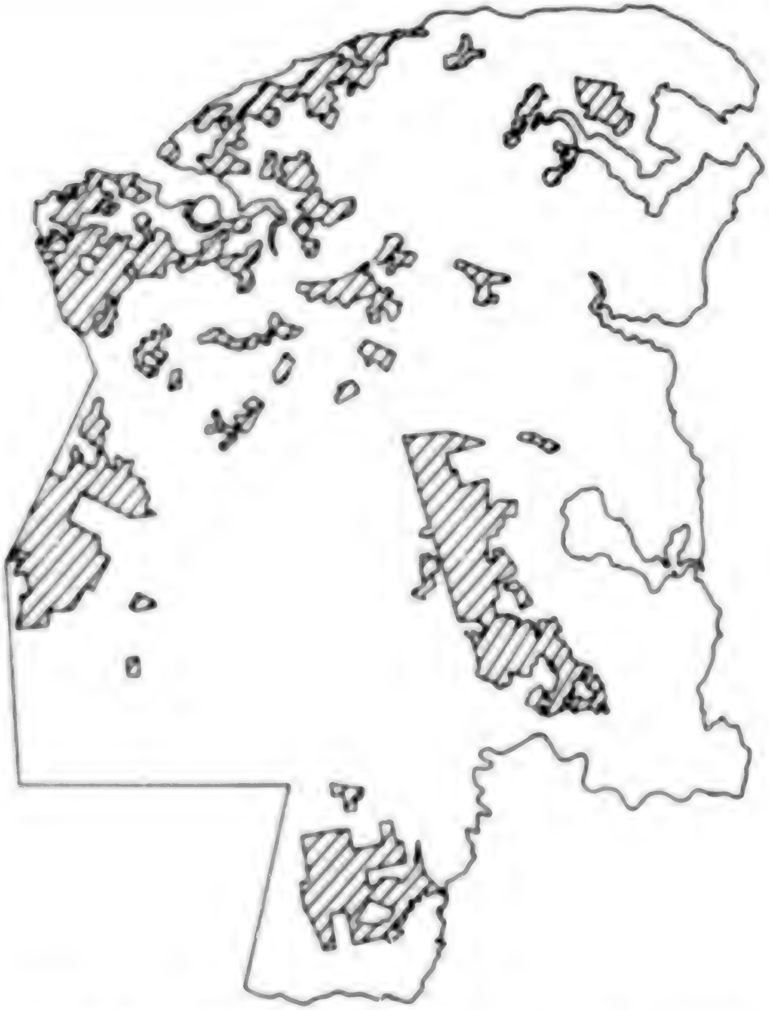

Figure 16. Farmland in Tyrrell County, North Carolina, 1974 (from Daniel 1978).

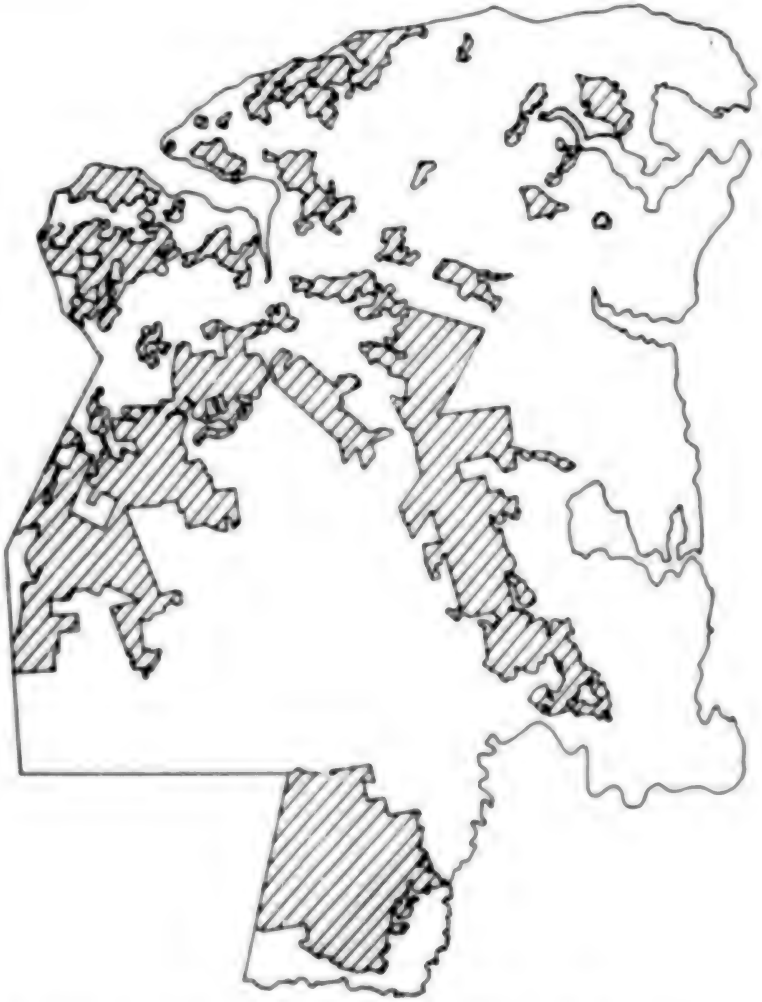

Figure 17. Farmland in Tyrrell County, North Carolina, 1980 (from Lukin and Mauger, in preparation).

agriculture with only minor improvement. With major canals in place, field ditches are surveyed parallel to one another and about 100 m (330 ft) apart. Rights-of-way are cleared for ditching equipment (Figure 18) and V-ditches 0.6-1.2 m (2-4 ft) deep are dig with a backhoe (Figure 19) (Lilly 1981a). If there is any marketable timber, canal roads and field ditches help provide access for logging machinery. Once ditching and logging are complete, clearing can begin. All surface vegetation, stumps, and accessible buried logs are pushed into long windrows midway between the field ditches (Figure 20), and spoil from the ditches is moved along with the vegetation to help "crown" the field. Windrows are usually removed by repeatedly burning and repiling until little residue remains (Figure 21). If the soil contains a large amount of buried wood, as it does in many deep organic soils, this must be dug out with bulldozers pulling large subsoilers that break logs and bring them to the surface (Lilly 1981a). Once sufficient buried wood has been removed, bulldozers are used in the initial leveling of the surface and heavy duty disks chop up roots and debris in preparation for final leveling. Land planes then produce an even slope of about 0.5% and the fields are ready for planting (Figure 22). Since plow furrows run parallel to field ditches, small breaks called hoe drains must be cut after planting to insure adequate drainage from furrow to field ditch (Doucette and Phillips 1978).

The latter stages of land clearing for forestry often differ from agriculture because forestry does not require perfectly "clean" fields. In forestry, subsurface logs, roots, and debris can be left in place if they do not interfere with tree planting. Also, adequate drainage for young seedlings is accomplished by planting in raised beds (Figure 23) which requires much less soil movement than "crowning" whole fields.

If land elevation is near sea level, ditch drainage is ineffective without the installation of boundary dikes constructed from canal spoil. These prevent flooding from storm tides and permit greater gradients for gravity flow within the drainage system. Either diesel or electric pumps are then installed to raise water over the dikes. These usually have capacities of about 190 m^3/min (50,000 gal/min) and are set up with two or three pumps at a station (Figure 24). Pumps run only during periods of maximum drainage demand, usually in spring, and usually for only 9 or 10 days a year under ideal circumstances (Steve Barnes, First Colony Farms, Creswell, NC, personal communication). In forestry, smaller portable pumps with capacities of about 57-95 m^3/min

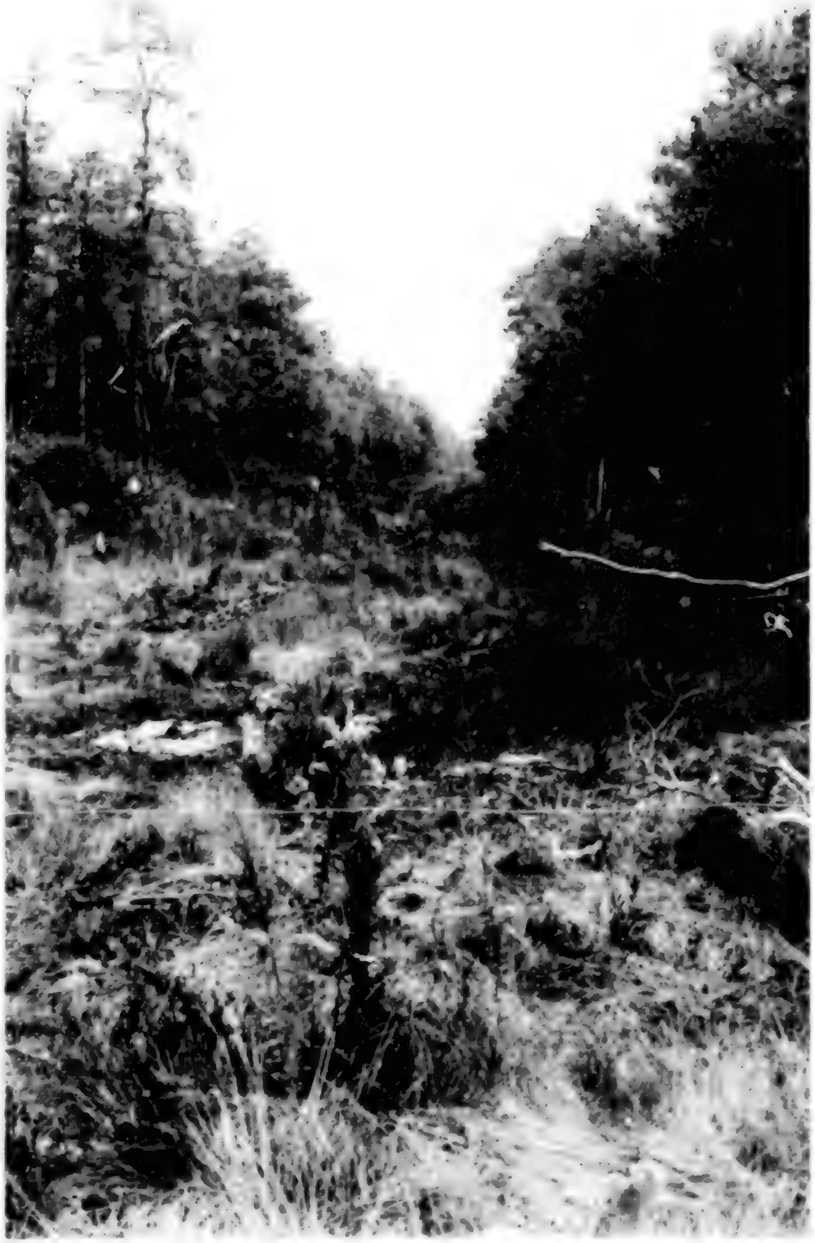

Figure 18. Right-of-way cleared for ditching equipment.

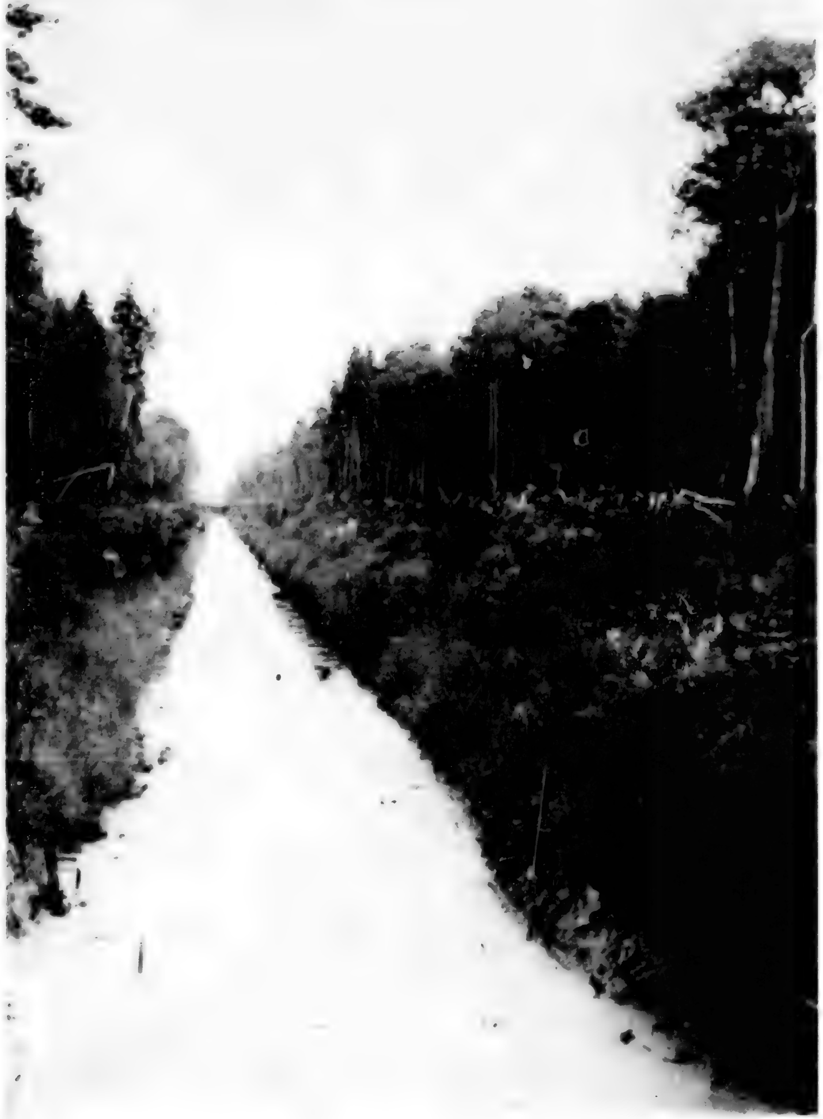

Figure 19. Newly-dug field ditch before logging.

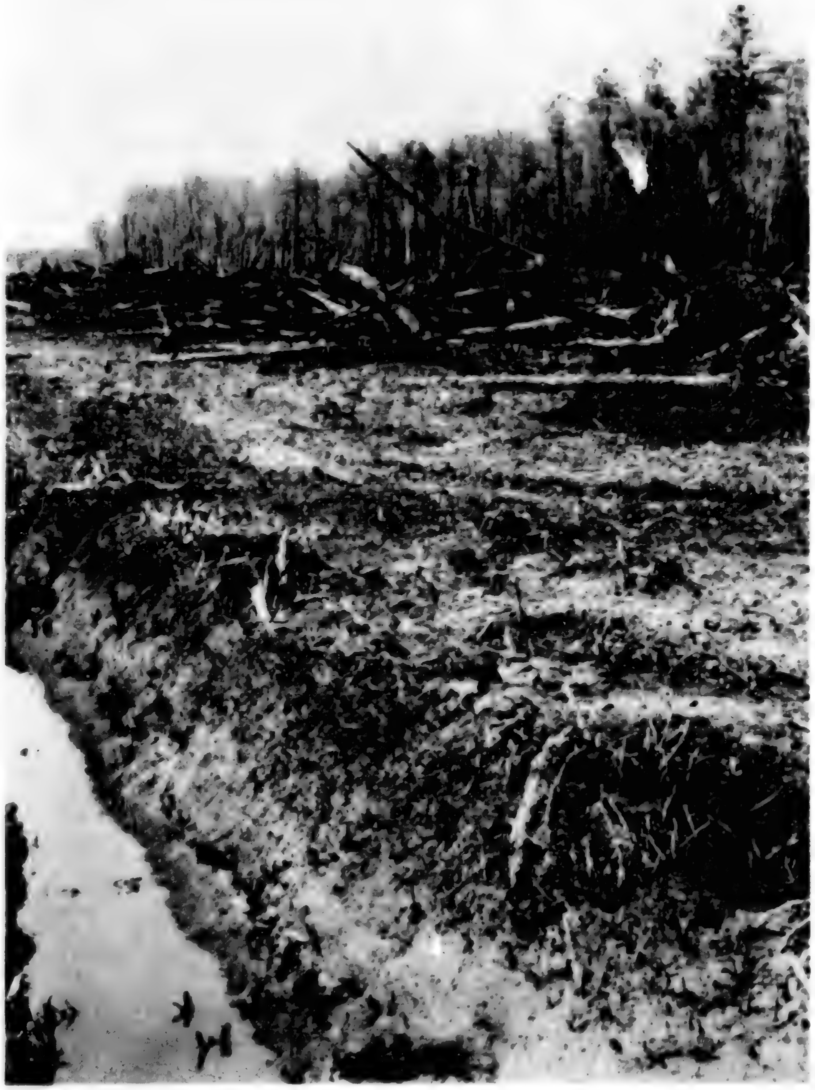

Figure 20. Windrow and field ditch in a newly cleared field.

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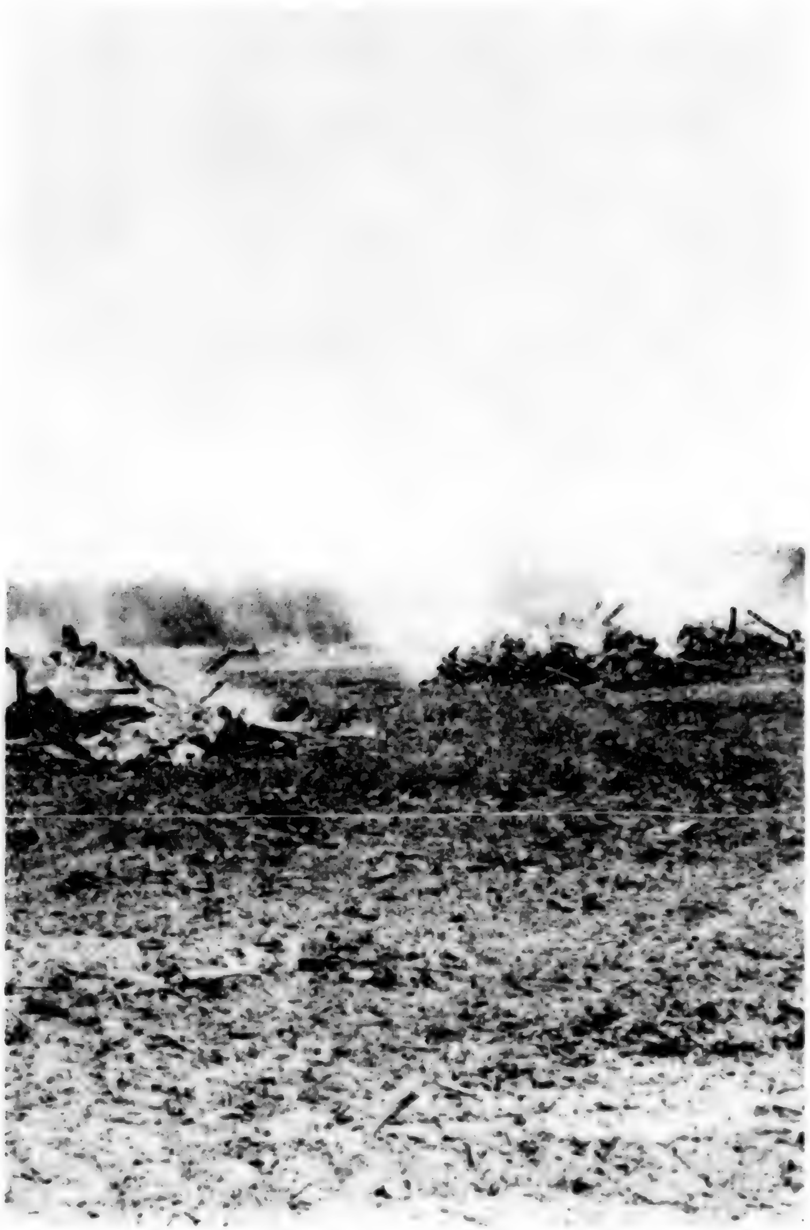

Figure 21. Burning stump piles.

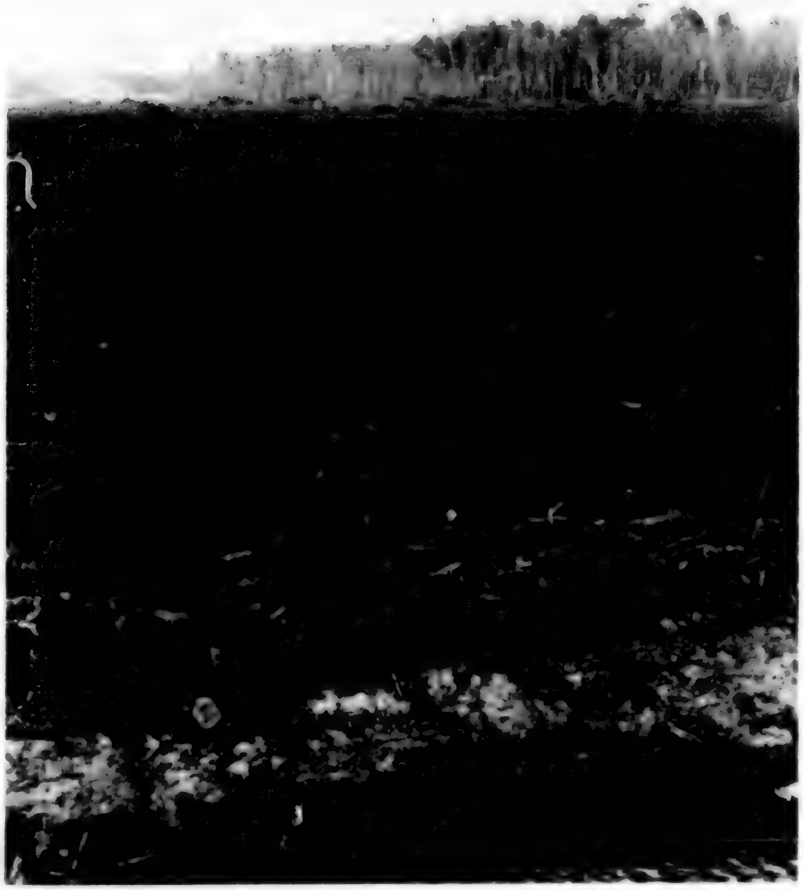

Figure 22. A new agricultural field developed from forested wetland.

(15,000-25,000 gal/min) are sometimes used for drainage either just prior to logging or during the early stages of regeneration (J. H. Hughes, Weyerhaeuser Corp., New Bern, NC, personal communication).

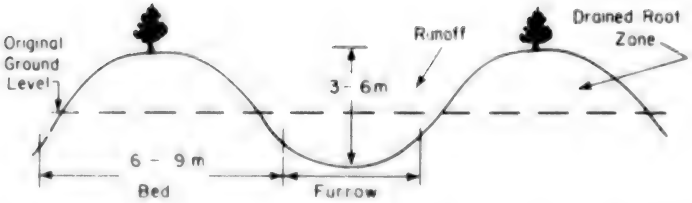

Figure 23. Diagram of bedding rows for pine seedlings (adapted from Doucette and Phillips 1978).

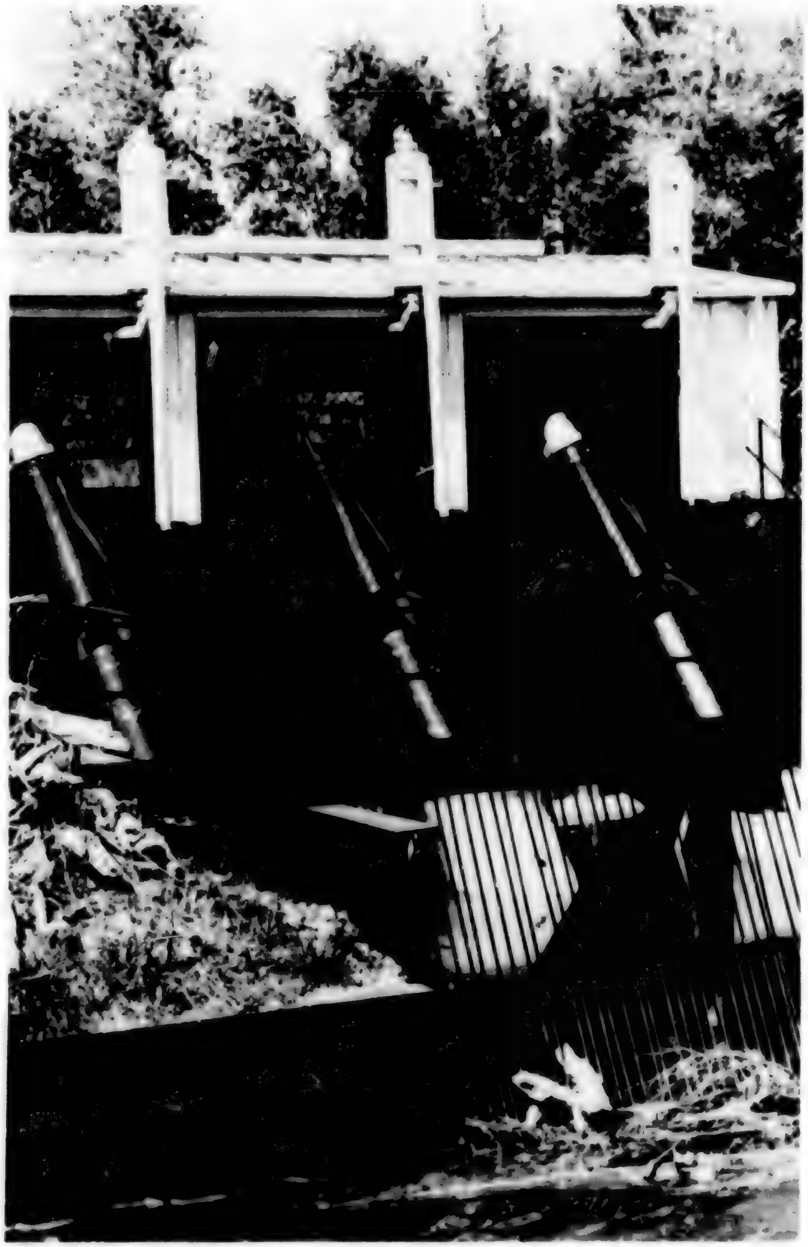

Figure 24. A diesel-powered pump station, Tyrrell County, North Carolina.

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CHAPTER 4. ALTERATION OF POCOSINS: HYDROLOGY AND WATER QUALITY

HYDROLOGY OF THE ALBEMARLE-PAMLICO REGION

The soil water table in highly organic eastern Coastal Plain soils tends to be independent of the geologic ground water table. Impervious subsurface layers keep water in the soil from seeping downward, and discharge takes place mainly by evapotranspiration and slow surface runoff through the relatively permeable upper layer of roots and litter. Since precipitation is fairly uniform throughout the year in this region, changes in hydrology are dependent primarily on seasonal changes in temperature which affect evapotranspiration. In winter, soils tend to become saturated and water may stand above the soil surface, while in summer the soil water table is lowered.

The Basic Water Budget

The following synopsis of hydrologic conditions in the Albemarle-Pamlico region is based on a discussion by Heath (1975). In any watershed, inputs of water as precipitation are balanced over the long term by outputs of water in evapotranspiration, overland runoff or surface drainage, and discharge to groundwater. The water budget of a region can be written as an equation (Heath 1975):

$$P = ET + OR + GWD$$

where P = precipitation

ET = evapotranspiration

OR = overland (surface) runoff[1]

GWD = discharge to groundwater

For the Albemarle-Pamlico peninsula, precipitation is the only term in the equation which has actually been measured (National Weather Service information). The other terms are derived indirectly. Slow water velocity, lack of discrete natural drainage channels, and tidal fluctuations have precluded the gathering of streamflow data by which the U.S. Geological Survey determines surface runoff in other regions. Therefore, overland runoff (OR) has been estimated by Heath by calculating the difference between precipitation inputs and the sum of evapotranspiration (ET) and discharge to groundwater (GWD). In turn, ET is estimated from values for standard pan evaporation and lake evaporation. The estimation of groundwater discharge is complex, depending on knowledge of the hydraulic characteristics of aquifers and gradients governing water movement. In this region, especially in Dare and eastern Tyrrell Counties, the contribution of GWD to the overall equation is comparatively small. Although estimates of water budget terms vary slightly depending on exact location, Heath's values can be assumed to be representative for the region. Under natural conditions of drainage,

$$P = 129 \text{ cm } (51 \text{ in})$$

$$ET = 91 \text{ cm } (36 \text{ in})$$

$$\text{and } GWD = 1.3 \text{ cm } (0.5 \text{ in}).$$

Thus, OR is estimated to be 37 cm (14.5 in).

Seasonal fluctuations in precipitation and evapotranspiration determine the actual water balance at different times of the year. When P is greater than ET, as in winter, the soil water storage capacity will often be exceeded and overland runoff will occur. During the growing season, ET will be higher than in winter when solar radiation and temperatures are lower. Basing ET values on pan evaporation times a coefficient of 0.7, Heath estimated that P at New Holland, North Carolina, exceeded ET every month except for April and May (Figure 25). Thus, if OR is determined mainly by the difference between P and ET, the periods of greatest runoff will be winter, late summer, and fall.

Changes in the Water Budget with Artificial Drainage

Basing his values for OR on runoff data from gaging stations on two creeks south of the Pamlico River and for GWD on the assumption that groundwater gradients would be lowered an average of 50% in the region as a whole, Heath estimated

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[1] Wilder et al. (1978) separate the runoff term into two components, overland runoff and groundwater runoff.

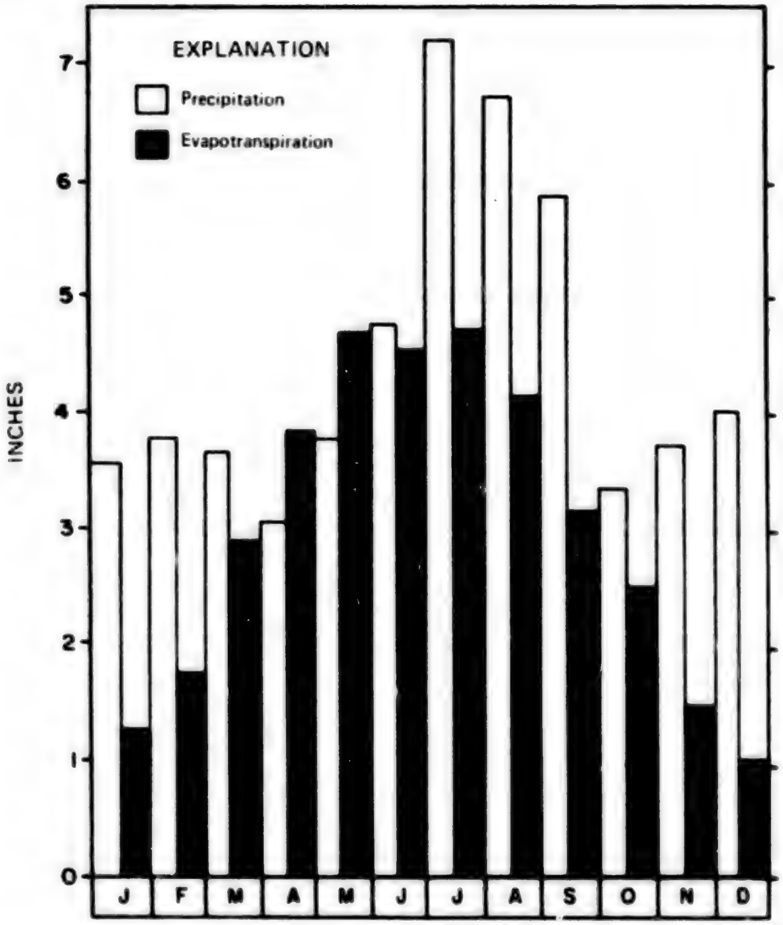

Figure 25. Monthly precipitation at New Holland, North Carolina, and evapotranspiration based on pan evaporation data from the Hofmann Forest (from Heath 1975).

that there would be little change in the hydrology of the region following intensive artificial drainage. Thus, the values in the after-drainage budget become:

$$P = 129.5 \text{ cm } (51 \text{ in})$$

$$OR = 39.4 \text{ cm } (15.5 \text{ in})$$

$$GWD = 0.6 \text{ cm } (0.25 \text{ in})$$

ET, by difference, would then be 89.5 cm (35.25 in).

Although Heath's water budget figures may be the best estimates presently available, it is possible that error in the approximations used for some factors such as ET in the before-drainage equation and OR in the after-drainage equation may exceed the estimated differences in the two budgets.

Total annual runoff. Daniel (1981) presented data suggesting that annual runoff in the Tidewater region may increase after artificial drainage and development. Daniel showed that total annual runoff as percent of rainfall may be greater in an agriculturally-developed area of the Albemarle-Pamlico peninsula than in natural areas (Table 3). Daniel's explanation for this is that conversion of wetlands to agriculture results in a reduction in interception of rainfall by vegetation as well as a reduction in residence time of water in the watershed, so that evapotranspiration has less opportunity to occur and a greater proportion of precipitation inputs are available for discharge as runoff.

Skaggs et al. (1980) compared "developed" and "undeveloped" sites on First Colony Farms in Tyrrell County, all of which previously had been ditched for drainage. There were significant differences in hydrology between sites that had merely been ditched and those that had undergone further development (clearing, removal of "root mat," and shaping in the case of cropland) to agriculture or pasture. Water budget terms were compared between paired developed and undeveloped sites on three different soil types in Tyrrell County: deep organic, shallow organic, and mineral soils having an organic surface layer. Rainfall on these sites varied between 102 and 130 cm per year while total annual runoff varied from 36-70 cm per year. Total annual runoff (mainly composed of surface runoff, but with small amounts of subsurface runoff into ditches) was measured in the drainage ditches and found to be only slightly higher for the developed than for the undeveloped mineral soil sites (Table 4). For the shallow organic sites, results were more variable, with a greater spread in runoff between developed and undeveloped sites except for one year (1978) when runoff on the undeveloped site was slightly higher than the developed site. For the deep organic sites, which were more distant from each other, there was higher annual rainfall as well as higher annual runoff from the undeveloped site than from the developed site. The percentage of rainfall which left the land as runoff, however, was highly variable for both sites.

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Table 3. Total annual runoff as percent of annual rainfall (cm)[a] on three sites on the Albemarle-Pamlico peninsula (from Daniel 1981).

	1977		1978		1979	
Drainage Area	Rainfall	% Runoff	Rainfall	% Runoff	Rainfall	% Runoff
North Lake Canal, Pungo Nat. Wildlife Refuge (nat. pocosin)	99.1	40%	135.0	56%	118.4	26%
Van Swamp (forested swamp)	-	-	123.7	63%	134.4	34%
Albemarle Canal (agriculture)	-	-	135.7	65%	125.0	41%

[a] 2.54 cm = 1 inch.

Table 4 Summary of total annual rainfall and runoff (cm)[a] for three soil types on First Colony Farms (from Skaggs et al. 1980).

		1976			1977			1978		
Site		Rainfall	Runoff	Percent	Rainfall	Runoff	Percent	Rainfall	Runoff	Percent
Mineral	Crop	-	-	-	102.8	26.0	25.3	130.8	57.2	43.7
	Undev.	-	-	-	102.8	23.4	22.8	130.8	55.1	42.1
Shallow Organic	Crop	63.6	28.3	44.5	126.0	69.6	55.2	104.0	55.0	52.8
	Undev.	63.6	21.0	33.0	126.0	51.6	40.9	104.0	57.4	55.2
Deep Organic	Pasture	53.1	11.6	21.8	96.4	42.5	44.1	88.1	36.9	41.9
	Undev.	58.8	8.7	14.8	121.5	50.0	41.1	129.2	65.0	50.3

[a] 2.54 cm = 1 inch.

From these results it appears that at present there is insufficient evidence to demonstrate whether total annual runoff is increased by agricultural development (clearing, removal of root mat, and shaping) of pocosin lands which have been previously ditched for drainage. When artificial drainage canals and ditches are excavated to a level below the contact of the organic soil and mineral subsurface layer, base flow from the mineral layer may add to ditch flow, thus increasing discharge into receiving estuaries (Daniel 1981). As suggested by Heath (1975), additional information gained by intensive gaging of flows in individual drainage canal watersheds would be useful in quantifying actual runoff.

Peak runoff rates. It is well documented that wetlands, including pocosins, tend to retain and store water from storms when the water level is below the surface of the wetland. This storage capacity can decrease the velocity and increase the time over which storm waters leave the land (Daniel 1981). Clearing and agricultural development of pocosin lands can result in substantial changes in the timing, duration, and discharge rates of flood waters. Discharge records show that peak discharges are higher and between-flood recessions are lower in the Albemarle Canal (which drains an intensively farmed area) than in Van Swamp (which drains a naturally forested area), even though the total annual runoff for the two areas is similar (Daniel 1931). Skaggs et al. (1980) found that peak runoff rates were three to four times higher from developed agricultural sites than from naturally-vegetated undeveloped sites on all three soil types under study. Peak runoff from the developed sites also occurred 6 to 24 hours earlier than from undeveloped sites following storms.

The relationship between peak runoff discharges and water table depth is shown by data from the Pungo National Wildlife Refuge, where peak runoff rates increased with decreasing depth to water table (Daniel 1981). Thus, during periods of high water table elevation, such as winter and early spring, peak runoff rates will be higher than in periods when the water table is lower. Movement of water through surficial peat, which is often poorly decomposed and thus relatively permeable to water, tends to occur more rapidly than through deeper peat layers which are more highly decomposed and less permeable. When the water table rises to a level within the surface peat, release of water as runoff will occur more readily than if the water table is within the less permeable deeper peat.

Water table. Water table depths on First Colony undeveloped mineral and shallow organic soils were lower than on the corresponding developed sites (Table 5). (The undeveloped mineral soil site was in harvestable timber; vegetation on the undeveloped shallow organic site was "natural".) On the deep organic soils, however, the water table on the developed site (in pasture) averaged 21 cm lower than the water table on the undeveloped site (in pocosin vegetation). Apparently differences in water table depth after ditching depend on both land use and vegetation. Comparison between the pair of sites on the deep organic soil resembled the comparison between a ditched vs. an unditched site, since the undeveloped site had only a collector ditch, while the developed site had a collector ditch and field ditches spaced 100 m apart as well. Since both of these sites were of similar size (130 ha), the effect of the

Table 5. Average annual water table depth, in meters below ground level, near the center of developed and undeveloped sites on First Colony Farms (from Skaggs et al. 1980).

Year	Mineral Soils		Shallow Organic Soils		Deep Organic Soils[a]	
	Crop	Undev.	Crop	Undev.	Pasture	Undev.
1976[b]	-	-	0.28	0.87	0.63	0.44
1977	0.49	0.74	0.40	0.89	0.58	0.38
1978	0.52	0.73	0.66	1.18	0.58	0.33
1979[c]	0.50	0.48	0.84[d]	1.14[d]	0.51	0.29

[a] Pasture site was more intensively ditched than undeveloped site, which had only a collector canal.

[b] Data collected for latter half of year, 8/1 through 12/31.

[c] Data collected for first half of year, 1/1 through 8/31.

[d] Averages of data collected from 3/5 through 8/31.

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increased density of ditching could be contributing substantially to water table reduction on the developed site. The comparison between these 2 sites, therefore, may give an approximation of the actual water table reduction in ditched vs. unditched areas.

WATER QUALITY OF RUNOFF FROM AGRICULTURAL LANDS

Much concern has been expressed about the effects of agricultural conversion of pocosin areas, including increased amounts and pulses of fresh water delivery, sediment erosion, and nutrient and pesticide loading on water quality of runoff waters and ultimate additions to receiving estuaries (Heath 1975).

Nutrients can enter runoff both through fertilization and from release of naturally present soil nutrients by soil disturbance. Organic soils surrounding Lake Apopka, Florida, were found to contribute substantial quantities of nutrients naturally present in the soils to the lake, regardless of the presence or absence of fertilizer, when they were drained and cultivated (Hortenstine and Forbes 1972). Erosion of a British peat land was found to result in exports of nitrogen, phosphorus, and other soil nutrients in runoff (Crisp 1966).

In an effort to follow changes in water quality of runoff as land development proceeded from natural swamp forest to intensive agriculture, Kirby-Smith and Barber (1979) monitored natural streams and drainage ditches on Open Grounds Farm in Carteret County, N.C. Data were collected prior to the addition of fertilizer nutrients which would be used for normal row-crop farming. Turbidity in drainage ditches was 10-20 times higher than the naturally low values found in a pocosin stream; pH increased toward neutrality from naturally acidic stream runoff; and nutrient concentrations increased approximately 5-10 times over naturally occurring concentrations (Table 6). Although discharge was not quantified, the highest concentrations of nutrients were often associated with high discharge rates, magnifying the total quantity of nutrients reaching the estuary.

At present, additional N, P, K, Cu and adjustment of pH with lime are necessary for agricultural development of North Carolina organic soils. North Carolina Histosols tend to be high in nitrogen, ranging between 0.6-2.6%, but about 70% of the nitrogen is composed of humic and fulvic acids which are very resistant to breakdown and thus unavailable to plants (Tonapa 1974, cited in Lilly 1981a). Thus, further amendments with available forms of N are necessary for crop growth. Concentrations of phosphorus vary with specific soil type, but additional P is generally required for optimum plant growth (Barnes 1981). Available copper is low and may be complexed with organic matter (Barnes 1981). Since all of these soils have low pH, heavy lime applications are needed, about twice as much, initially, as required by coarser-textured mineral Coastal Plain soils. Thereafter, lime can be applied at about the same rate as other Coastal Plain soils (Barnes 1981). The proposed fertilization schedule for First Colony Farms is given in Table 7.

Table 6. Nutrient concentrations from a natural stream and agricultural drainage ditches on Open Grounds Farm following development (from Kirby-Smith and Barber 1979).

Parameter	Natural Stream	Drainage Ditches[a]
Turbidity (JTU)[b]	1.0 - 5.4	5.6 - 146
pH	3.4 - 5.4	4.3 - 7.9
PO_4 (mg P/l)	0.006 - 0.026	0.006 - 0.790
NO_3 (mg N/l)	0.003 - 0.017	0.003 - 0.66
NH_4 (mg N/l)	0.004 - 0.153	0.004 - 1.28

[a] Composite of values for three ditches.

[b] Jackson Turbidity Units.

Nitrogen

Concentrations of nitrogen in runoff water from paired developed/undeveloped sites on three soil types on First Colony Farms are given by Skaggs et al. (1980). Concentrations of nitrate nitrogen (NO_3-N)[2], ammonia nitrogen (NH_4-N), and organic nitrogen (total Kjeldahl N) averaged

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[2] Amounts of nitrite nitrogen (NO_2-N) in runoff water would be negligible and would be included in the measurement of nitrate.

Table 7. Proposed schedule of fertilization for First Colony Farms agricultural land (S. Barnes, personal communication).

Fertilizer	Application Rates kg/ha (lb/ac)	
	New Lands	Continuing Agricultural Use
P as P_2O_5	168 (150)	45-56 (40-50)
K as K_2O	112 (100)	45-56 (40-50)
N (for corn only)	157-179 (140-160)	157-179 (140-160)
Cu	3.4-5.6 (3-5)	1.1 (1) every 5 yr
Lime	9,000-18,000 (8,000-16,000)	2,240 (2,000) every 3 yr

150-900% higher in runoff from the developed vs. the undeveloped sites, and were especially high on the mineral soils (Table 8). In addition, yearly average concentration of all measured forms of nitrogen increased from one year to the next in runoff from the developed mineral soil, while concentrations in runoff from the undeveloped mineral site showed no consistent trend. There was some tendency for N concentrations in runoff to increase with time for the developed shallow organic site as well (Table 8). On several sampling dates over the three-year period of the study, inorganic N (NO_3-N and NH_4-N) concentrations in runoff from developed soils reached levels in the range of 8-24 mg/l (Appendix D, Skaggs et al. 1980). Concentrations of inorganic forms of N in runoff from developed agricultural lands on First Colony Farms are generally as high or higher than in two streams draining large agricultural areas of the North Carolina Piedmont, but lower than in municipal sewage effluent (Table 9).

Development of soils was shown in the study by Skaggs et al. (1980) to lead to a significant increase in the total quantity of N leaving the land in runoff. In the last year of the study, this quantity was 0.6 kg/ha NO_3-N and 0.7 kg/ha NH_4-N from the developed shallow organic soil and 6.3 kg/ha NO_3-N and 5.4 kg/ha NH_4-N from the developed mineral soil. Inorganic forms of N (NO_3-N and NH_4-N) are of most concern in runoff to estuaries since these forms can be readily utilized by aquatic algae, in contrast to organic N (Kjeldahl N) which must undergo mineralization in order to become available to plants. The total flux of inorganic forms of N (NO_3-N and NH_4-N) leaving the land increased each year on the mineral soils. Quantities of inorganic N in runoff from the developed mineral and shallow organic soils were generally much higher than from the undeveloped sites on these soils. Although fluxes of NO_3-N from all soils were much lower than fluxes from some upland soils in North Carolina (30-40 kg/ha/yr) (Gilliam et al. 1978) and from organic soils in New York (40-90 kg/ha/yr) (Duxbury and Peverly 1978), the cumulative effect of numerous small increases in N fluxes resulting from large-scale agricultural activities draining at close range into estuaries may warrant further study.

The amount of N which leaves agricultural land in runoff is highly dependent on the timing and intensity of precipitation. Large storms can lead to a greater loss within a few days than in an entire year (Gambrell et al. 1975b). Nutrient concentrations in runoff from organic soils were found to be higher in periods of high flow (Duxbury and Peverly 1978), possibly related to intensity and duration of precipitation. Attempts to correlate nutrient concentrations

Table 8. Weighted averages and ranges of nitrogen concentrations in drainage water from developed and undeveloped sites on First Colony Farms (from Skaggs et al. 1980).

		Mineral Soil		Shallow Organic		Deep Organic	
Nitrogen Form	Year	Crop	Undev.	Crop	Undev.	Pasture	Undev.
		mg/l					
NO_3-N	1976[a]	0.05	0.58	0.12	0.02	0.44	0.01
	1977	0.60	0.15	0.11	0.06	0.20	0.05
	1978	0.76	0.06	0.50	0.07	0.22	0.02
	1979	2.20	0.03	0.44	0.01	0.11	0.01
	Average[b]	1.00	0.11	0.29	0.05	0.21	0.03
	Range	0.00-13.70	0.00-1.69	0.00-9.12	0.00-0.06	0.00-2.12	0.00-0.40
NH_4-N	1976[a]	0.13	0.11	0.31	0.10	0.35	0.09
	1977	0.52	0.17	0.12	0.10	0.42	0.10
	1978	0.72	0.18	0.45	0.24	0.42	0.10
	1979[a]	1.86	0.10	0.25	0.14	0.24	0.15
	Average[b]	0.91	0.15	0.28	0.16	0.37	0.11
	Range	<0.1-15.5	<0.1-26.7	<0.1-3.3	<0.1-1.4	<0.1-1.8	<0.1-0.8
Total Kjeldahl N[c]	1976[a]	1.23	1.14	2.25	1.07	1.68	1.21
	1977	2.14	0.86	2.03	1.00	1.78	1.17
	1978	2.63	0.81	2.28	0.96	1.62	1.08
	1979[a]	3.98	0.74	3.14	1.08	1.63	1.25
	Average[b]	2.73	0.82	2.36	1.02	1.67	1.15
	Range	0.34-24.6	0.00-10.0	0.20-18.9	0.08-3.22	0.64-15.1	0.34-4.06

[a] Measurement period in 1976 was for last six months of year and in 1979 for first six months of year. The mineral soil was not cleared and cropped until 1977, so both sites on this soil were in trees in 1976.

[b] Average is for three years starting in July 1976.

[c] Includes organic nitrogen and ammonia (Amer. Public Health Assoc. 1976).

Table 9. Nitrogen and phosphorus concentrations in some North Carolina surface waters and municipal sewage effluent.

	Nutrient, mg/l			
Source	NO_3-N	NH_4-N	Filterable Reactive or Dissolved P	Total P
Unpolluted streams in North Carolina[a]	0.01-0.17	0.00-0.02	--	0.01-0.03
Tar River at Tarboro[b]	0.29-0.86	0.01-0.09	0.01-0.23	0.00-0.33
Roanoke River at Roanoke Rapids[b]	0.04-0.27	0.00-0.12	0.00-0.23	0.02-0.24
Tar River Swamp surface water[c]	0.01-0.71	0.01-0.05	0.03-0.44	0.06-1.74
Secondary sewage effluent from Greenville, N.C. treatment plant[c]	0.38-5.38	7.24-36.9	1-5	3.3-5.6

[a] Simmons and Heath 1982, p. B24. Mean concentrations in low to high flows.

[b] U.S. Geological Survey 1980, pp. 65 and 46.

[c] Brinson et al. 1981a, pp. 38-39 and 32-33.

to flow rates on First Colony lands were inconclusive because of the inadequate capacity of drainage outlets which tended to slow water velocity and cause the water level to rise (Skaggs et al. 1980), but do not rule out a potential relationship between high runoff rates and high nutrient concentrations.

Denitrification processes operating in poorly drained soils can act to remove substantial amounts of nitrogen to the atmosphere as N_2 or N_2O gas, and thus reduce the quantities available for discharge in runoff. Denitrification has been demonstrated in poorly drained North Carolina soils (Kilmer et al. 1972, Gambrell et al. 1975a, Gilliam et al. 1978). Nitrate accumulates during dry conditions and is then denitrified during subsequent wet conditions (Patrick and Tusneem 1972). However, nitrate may continue to be lost in drainage water for a period of time after a return to the normal high water table following dry spells, until sufficient time has elapsed for denitrification rates to become effective once more (Gambrell et al. 1975a).

Phosphorus

Phosphorus inputs to surface waters in the U.S. originate mainly from rural land runoff (Porcella and Bishop 1974). The proportion of land used for agriculture within a watershed can significantly affect phosphorus content of streams. In North Carolina, concentrations of phosphorus in storm runoff are 2 to 13 times higher than baseline levels when agricultural land use in watersheds is 20% or more (Simmons and Heath 1982). Baseline levels were established from stream basins in which non-forested land uses were 10% or less. In the Kissimmee River Basin of Florida, increased drainage density (length of the artificial surface drainage network per unit area of land) was found to be correlated with increased total phosphorus concentrations in the river (Huber et al. 1976). In the Chowan basin of North Carolina, agricultural land use has been estimated to contribute 44% of total phosphorus loading to the Chowan River, calculated using nutrient loading rates from the literature and acreage of land in agriculture (N.C. Div. of Envir. Management 1982). When nutrient loading was calculated by a mass-balance method, phosphorus loading from agricultural sources was estimated to be 72% (Craig and Kuenzler, 1982).

Phosphorus is generally regarded as a critical factor in eutrophication of freshwater lakes, with the potential for algal blooms at concentrations as low as 0.01 mg P/l (Porcella and Bishop 1974). In the Chowan River, phosphorus in agricultural drainage has been identified as the major contributor to nuisance blue-green algal blooms (N.C. Div. of Envir. Management 1982). The North Carolina Division of Environmental Management has recommended that phosphorus loading to the Chowan River, including both point and non-point sources, be reduced by 30-40% in order to minimize the occurrence of future blooms (N.C. Div. of Envir. Management 1982).

Phosphorus concentrations and fluxes in runoff water were generally much higher from developed shallow and deep organic soils on First Colony Farms than from developed mineral soil or from any of the undeveloped soils. Concentrations averaged 1.21 and 2.48 mg P/l for the developed shallow and deep organics and 0.14 mg P/l for the mineral soil (Table 10) (Skaggs et al. 1980). Monitoring over a limited period of time showed that most of the phosphorus in drainage from shallow and deep organic soils on First Colony Farms was in the soluble form of orthophosphate (Appendix F in Skaggs et al. 1980), a form that is easily available for utilization by phytoplankton (Porcella and Bishop 1974). From the shallow and deep organic soils, P concentrations were generally much higher than concentrations in two principal farmland-draining rivers, the Tar and the Roanoke (Tables 9 and 10), while from mineral soils, phosphorus concentrations were in the same range as the rivers.

Phosphorus fluxes (amounts of phosphorus lost from the land in drainage water) from the shallow and deep organics on First Colony land were also several times higher than losses from organic soils in other regions. First Colony developed organic soils exported on the average 7.64 and 9.54 kg P/ha/yr in comparison to 1.45 kg P/ha/yr from organic soils on Michigan State University lands (Erickson and Ellis 1971) and 1.6 kg P/ha/yr from Ontario marsh drainage (Nicholls and MacCrimmon 1974). However, the First Colony phosphorus losses were much less than the 17-32 kg P/ha/yr lost in drainage water from New York State cultivated muck soils (Duxbury and Peverly 1978).

The amount of phosphorus lost in runoff is affected by soil characteristics at the location where fertilizer is applied as well as the soil through which drainage water passes. Phosphorus fertilizer tends to remain in solution in soils of high organic matter content while higher mineral content tends to increase the capacity for phosphorus fixation (Fox and Kamprath 1971). Leaching of reactive phosphorus in runoff was much lower when subsurface drainage was through mineral soil rather than organic soil (Duxbury and Peverly 1978). Hortenstine and Forbes (1972) recommended allowing runoff to percolate through marl in Florida lands in order to remove P before runoff reached Lake Apopka. Skaggs et al. (1980) stated that mineral sediments in ditch bottoms should help remove P from runoff while in transit. However, Hill and Sawhney (1981) found that the capacity of an experimental soil block to adsorb phosphorus was significantly reduced with continued inputs of wastewater containing 12 mg P/l, especially under anaerobic conditions. Duxbury and Peverly (1978) cautioned against relying upon contact with sediment to protect receiving waters from phosphorus pollution because of potentially limited contact of water with mineral material, limited fixation capacity of mineral material, slow kinetics of fixation, or a combination of these factors.

Unlike nitrogen, phosphorus is not affected by an atmospheric pathway and cannot easily be removed from the soil-water system except by plant uptake. When the limit of phosphorus fixation capacity by sediments is reached, there will be a net release of phosphorus from sediments, which will then act as a source rather than a sink for the element (Porcella and Bishop 1974). Also, although phosphorus may accumulate in ditch-bottom sediments during low flows because of net deposition of sediment under low velocity, phosphorus outflushing associated with sediment transport can occur during high flows following storms (Sloey et al. 1978). Resuspension of phosphorus in sediment pore water by physical mixing of sediments under high-flow conditions led to increased concentrations of phosphorus in the Kissimmee

Table 10. Concentrations and annual fluxes of total phosphorus in drainage waters from developed and undeveloped sites on First Colony Farms (from Skaggs et al. 1980).

		Mineral Soil		Shallow Organic		Deep Organic	
	Year	Developed	Undeveloped	Developed	Undeveloped	Developed	Undeveloped
Average concentration, mg/l	1976[a]	0.06	0.13	1.33	0.02	2.27	0.05
	1977	0.08	0.07	1.75	0.06	3.22	0.10
	1978	0.17	0.05	0.87	0.03	2.23	0.05
	1979	0.13	0.01	0.49	0.03	1.73	0.04
	Average[b]	0.14	0.05	1.21	0.04	2.48	0.06
	Range	0.01-4.29	0.00-3.91	0.01-5.36	0.00-0.44	0.07-4.48	0.00-1.83
Average flux, kg/ha/yr	1976[a]	0.07	0.10	3.58	0.05	1.85	0.05
	1977	0.22	0.17	12.53	0.31	12.44	0.53
	1978	1.01	0.25	5.13	0.19	8.70	0.33
	1979	0.35	0.04	1.52	0.07	4.08	0.13
	Average[b]	0.56	0.20	7.64	0.21	9.54	0.35

[a] Measurement period in 1976 was for last six months of year and in 1979 for first six months of year. The developed mineral soil site was not cleared until 1977, so flux in 1976 was for a natural area.

[b] Average is for a three-year period starting in July 1976.

River, Florida, during floods. This release is due to the gradient established between high levels of sediment pore water P and low levels of P in relatively dilute storm water; as a result sediments act temporarily as a source and phosphorus is discharged downchannel in runoff (Burton et al. 1976).

Sediment

Sediment from soil erosion is generally the principal pollutant of surface water (Stewart et al. 1975). The problem of soil erosion can be viewed in two ways. From the farmer's point of view, soil erosion represents loss of soil resources from agricultural land which can ultimately result in decreased crop yields. From the point of view of the fisherman or the fish and wildlife agency, soil erosion means sediment and associated materials delivered to receiving waters as pollutants. Not all soil which is lost from fields will eventually reach water bodies. "Sediment delivery ratios" have been calculated by the Soil Conservation Service to estimate the proportion of soil removed from the land that is deposited at points downstream. This ratio varies from about 0.08-0.33 of gross erosion and is approximately inversely proportional to watershed area. Multiplied by gross erosion, it gives an estimate of sediment yield to receiving waters (Stewart et al. 1975). Sediments reaching water bodies will also be different in composition from those which left the land. This is because some eroded soil is redeposited elsewhere on the land or in drainage channels and this redeposition is selective; in other words, coarser particles are more likely to settle out than finer particles.

In addition to direct soil losses, losses of nutrients and pesticides are strongly associated with soil erosion because these compounds may be adsorbed by soil particles, particularly fine particles such as silts and organic matter. Thus, determining soil losses for a region can help in estimating the amounts of nutrients and pesticides in runoff which may reach receiving waters. Soil loss is usually determined by using the Universal Soil Loss Equation, which involves knowledge of several factors (U.S. Soil Cons. Serv. 1981):

$$A = R\ K\ LS\ C\ P$$

A = computed weight of soil loss per unit area per unit time, usually expressed in tons per acre per year

R = rainfall erosion index

K = soil erodibility factor (for surface layer)

L = slope-length factor

S = slope-steepness factor (combined into LS)

C = cover and management factor

P = support practice factor (ratio of soil loss with erosion-control practice to soil loss with straight-row farming)

Since other factors in the equation vary with cropping and management practices, the best overall idea of potential soil loss for the region can be obtained from factors K and LS. Erodibility values of some soil types for Tyrrell County are given in U.S. Soil Cons. Serv. (1981). However, values for K have not been assigned by the Soil Conservation Service for soils containing more than 4% organic matter, and detailed descriptions of soil types are not available for many of the soils in Hyde and Dare Counties; instead, many soils in these two counties are classified in the general soil groups described as very poorly drained mineral, shallow organic, or deep organic soils (Lukin and Mauger, in preparation).

Because of the flat topography, runoff erosion problems of Blacklands soils are not as severe as those of the Piedmont sections of North Carolina. In the Washington-Tyrrell-Hyde County region, soil losses have been estimated to be less than 5 ton/ac/yr (13 X 10^3 kg/ha/yr), whereas in the Piedmont these losses may be 15-20 ton/ac/yr (39-52 X 10^3 kg/ha/yr) (R. Croom, Soil Conservation Service, Plymouth, NC, personal communication). Nevertheless, changes in land use from the original forest cover to agriculture can result in large increases in soil losses. This can be demonstrated by comparing hypothetical soil losses from the same soil type on naturally forested land with those on cropland under different management programs:

Soil Type: Weeksville silt loam
Universal Soil Loss Equation (USLE)

$$A = R\ K\ LS\ C\ P$$

R in Tyrrell County = 340 (U.S. Soil Cons. Serv. 1981, p. 6)

K for soil type = 0.43 (U.S. Soil Cons. Serv. 1981, p.22)

LS = 0.5 (assume slope of 1% and slope length of 150 ft; U.S. Soil Cons. Serv. 1981, p. 26)

For undisturbed forest land, 100% vegetative cover:

C = 0.001 (U.S. Soil Cons. Serv. 1981, p. 62)

P = 1.0 (no support practices; U.S. Soil Cons. Serv. 1981, p. 67)

A = (340) (0.43) (0.5) (0.001) (1.0) = 0.07 ton/ac/yr (157.6 kg/ha/yr)

For cropland (corn, small grain, soybeans rotation, conventional tillage):

C = 0.292 (line 84, U.S. Soil Cons. Serv. 1981, p. 40)

P = 0.62 (U.S. Soil Cons. Serv. 1981, p. 67)

A = (340) (0.43) (0.5) (0.292) (0.60) = 12.8 ton/ac/yr (28,690 kg/ha/yr)

For cropland (corn, small grain, soybeans rotation, no-till):

C = 0.077 (line 154, U.S. Soil Cons. Serv. 1981, p. 45)

P = 0.60 (U.S. Soil Cons. Serv. 1981, p. 67)

A = (340) (0.43) (0.5) (0.077) (0.60) = 3.4 ton/ac/yr (7620 kg/ha/yr)

These sample calculations indicate that the hypothetical increase in soil loss can be nearly fiftyfold when forested land is converted to agriculture, even when a supporting practice to reduce soil erosion, no-till farming, is employed. The loss is much greater when conventional tillage is used.

In addition, sediment yields to estuaries from the Piedmont are reduced by distance from the source and by the sediment-trapping effect of reservoirs and river floodplains. Piedmont fields tend to be small and interspersed with "buffer areas" of woodland and streamside vegetation which can trap sediment. This situation does not exist in areas of Hyde, Tyrrell, and Dare Counties where field sizes are commonly 10-50 km^2 (4-19 mi^2) and uninterrupted by natural vegetation. Agricultural lands in pocosin areas are much closer to estuaries, and runoff is routinely discharged through canals directly to estuaries.

With agricultural development of large areas of land, increases in soil erosion may result in significant cumulative yields of nutrients and agricultural chemicals to estuaries. Though sediment yields would be only a portion of soil losses from the land, nutrient and pesticide concentrations in sediment may be greatly enriched compared to their concentrations in soil. These compounds tend to be preferentially adsorbed on fine soil particles, such as silt and organic matter, which remain in suspension longer than coarser particles and thus have a greater opportunity to reach estuaries (Stewart et al. 1975).

Average sediment fluxes for developed crop soils on First Colony Farms were 316-592 kg/ha/yr (0.13-0.24 ton/ac/yr), 3.6-10.7 times higher than for comparable undeveloped soils (Table 11). The flux from developed pasture (on the deep organic soil) was 59 kg/ha/yr (0.024 ton/ac/yr), about 1.5 times higher than the paired undeveloped soil. (Presumably, this difference reflects the higher amount of tillage and soil disturbance taking place on cropped land than on pasture). Mean concentrations for sediment in drainage water were not calculated in this study. However, concentrations of filterable sediment from the developed shallow organic soil showed a definite increase over the

Table 11. Average sediment fluxes for sediment particles >0.45 μm diameter and turbidity in drainage water from developed and undeveloped sites on First Colony Farms (from Skaggs et al. 1980).

Parameter	Mineral Soils		Shallow Organic Soils		Deep Organic Soils	
	Crop	Undev.	Crop	Undev.	Pasture	Undev.
Sediment flux, kg/ha/yr (tons/ac/yr)	316 (0.125)	87 (0.035)	592 (0.236)	55 (0.022)	59 (0.023)	37 (0.015)
Turbidity, JTU[a]	92	26	61	14	56	11

[a] Jackson Turbidity Units.

3-year sampling period (Appendix D in Skaggs et al. 1980). Similar trends were not apparent for the other developed or undeveloped sites.

Sediment impacts of agricultural development are difficult to determine from the report by Skaggs et al. (1980). Even though the authors conclude that these impacts are low and would be higher in the initial development phase than in normal agricultural operations, data presented in the Appendix do not show evidence for these conclusions. Sediment concentrations in drainage from developed shallow organic sites, in fact, show an increase over the three years of the study, which extends well beyond the "initial development" phase. In addition, records of sediment concentrations cannot be related to actual sediment fluxes on the same dates. It is impossible to extrapolate data from sediment concentrations taken at the edge of fields to estimate amounts that would actually be delivered to the estuary, since although sediment deposition may take place in low or normal flow conditions, periodic high-flow flushing related to storms could remove much sediment down-channel. Some of this sediment would likely be deposited in small creeks in which relatively sensitive spawning beds and nursery areas are frequently located. When delivered directly into these areas, sediment can cause local problems of siltation and light reduction which may have serious effects on aquatic organisms and habitat (Corbett et al. 1978).

Pesticides

Transport and fate of pesticides is extremely complex because of the diversity of compounds and their reactions in soils. Pionke and Chesters (1973) report that, for some pesticides, a greater proportion is carried with the sediment fraction than with the water fraction of runoff (for example, heptachlor may be distributed preferentially in a concentration ratio of 1:100 between water and sediment, and for other pesticides, the ratio may be 1:1000-2000). Strong adsorption of most nonionic pesticides is found in soils of high organic matter content. These compounds leave the land mainly by erosion of the colloids to which they are adsorbed rather than by leaching in solution, except for brief periods immediately following application before adsorption to soil colloids has taken place (Pionke and Chesters 1973).

Potential for microbial degradation of pesticides is related to pH and water status of the soil. Low pH and either drought or waterlogging of the soil are associated with low microbial activity. As a result, microbial degradation of some pesticides is retarded, and their persistence and the probability of contamination of receiving waters is increased (Pionke and Chesters 1973). Soil adsorption of pesticides often stabilizes them into a "pesticide-soil complex" which is resistant to degradation and which can then move by erosion to aquatic systems (Pionke and Chesters 1973). Conditions in receiving waters such as pH, salinity, temperature, and O_2 levels, as well as conditions in the sediments below, then determine their fate. Under some conditions, pesticides are then released in a soluble form from which they are either degraded rapidly, are rebound to other particles such as clays and organic matter in sediments, or are taken up by aquatic biota. In other cases, they may remain bound to sediment particles which settle to the bottom and from which subsequent changes in limnological conditions determine timing and rates of release.

Atmospheric inputs of pesticides to water bodies have been suggested to occur by wind erosion of soil particles. Low concentrations of chlordane, heptachlor, epoxide, dieldrin, and 2, 4, 5-T have been detected in rain associated with dust storms; and continuous inputs of low concentrations have an undetermined but potentially important effect on surface waters (Pionke and Chesters 1973).

Alachlor herbicide[3] persisted in the soil in measurable amounts as long as 248-335 days after application to First Colony lands (Skaggs et al. 1980). The investigators stated that this persistence may be caused by association of the herbicide with soil organic matter, making microbial degradation more difficult. Such persistence has not been found for mineral soils. Despite similar rates of application of alachlor to First Colony lands, variation of 1-2 orders of magnitude in alachlor concentrations in drainage ditch water was found in different years. This variation was attributed by the investigators to possible wind drift of the herbicide directly to the ditches. This inconsistency suggests that even with careful application, the amounts of pesticides discharged in drainage waters may not be subject to adequate control because of weather conditions.

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[3] 2-chloro-2', 6'-diethyl-N-(methoxymethyl) acetanilide; trade name Lasso.

Use of recently developed simplified predictive models which can be run by land managers may be of benefit in predicting runoff losses of different types of pesticides under various conditions (Haith 1980). Implementation of Haith's model requires information about pesticide degradation rates and the partition coefficient of pesticide between adsorption and desorption; as well as soil parameters such as available water capacity, bulk density, and retention and soil loss factors; and site data such as field area, rainfall, and pesticide application rates.

More comprehensive monitoring of other commonly used herbicides and insecticides in drainage waters of this area appears to be required in order to determine their persistence and transport. In addition, it seems urgent to determine the cumulative effects on receiving waters of extensive, long-term pesticide use on altered pocosin land in close proximity to valuable estuarine habitat.

Bacteria

Concentrations of fecal and total coliform bacteria were much higher in runoff water from developed sites than from undeveloped sites on both shallow and deep organic soils on First Colony Farms (Table 12) (Skaggs et al. 1980). This finding was not surprising for the developed deep organic site, which was used for grazing during the study; but a large increase in coliforms was not expected from the shallow organic site planted with row crops. The investigators suggest that high soil organic content combined with an increase in pH from liming on developed sites offers a survival advantage to coliforms.

Kirby-Smith and Barber (1979), in an investigation of coliform bacteria in waters draining from Open Grounds Farm and nearby locations, found that although coliform counts were often higher in areas disturbed by man, it was difficult to correlate bacterial numbers with particular land uses. Drainage waters from farmlands in this study contained coliform numbers which were not significantly higher than those from other man-modified systems. The investigators suggest that identification and elimination of sources of potential human contamination are more important than attention to animal sources, from which most of the fecal coliforms in this study were presumed to have originated.

Table 12. Average fecal and total coliform bacteria concentrations (numbers per 100 ml) measured in drainage water from organic soil sites on First Colony Farms (from Skaggs et al. 1980).

		Developed (crop)		Undeveloped	
Soil Type	Year	Fecal	Total	Fecal	Total
Shallow organic	1976	28	1665	29	441
	1977	207	1091	9	139
	1978	193	2054	28	313
		Developed (pasture)		Undeveloped	
	Year	Fecal	Total	Fecal	Total
Deep organic	1976	730	2672	18	132
	1977	1242	2665	5	71
	1978	1181	2231	17	117

Although the significance of high numbers of coliforms in the absence of human sources is uncertain, the finding of sufficiently high counts[4] in waters over shellfish growing beds from any source generally constitutes grounds for closing these waters to commercial oyster and clam harvesting. Coliforms themselves are not considered pathogenic but are indicators of the potential presence of human pathogens.

Aeromonas hydrophila, isolated as the causative agent of red sore disease of fish in Albemarle Sound (Esch and Hazen 1980), has been responsible for fish kills in Albemarle Sound and other areas of North and South Carolina and Florida, as well as for cases of human infection (Hanson et al. 1977, Fulghum et al. 1978). Esch and Hazen reported that densities of *A. hydrophila* showed significant positive correlations with numbers of coliforms, chlorophyll *a*, pheophytin *a*, sulfate, ammonia, total nitrogen, phosphates, total phosphorus, and total organic carbon. Densities were negatively correlated with dissolved oxygen concentrations and turbidity. The strongest relationships were found with phosphates and total phosphorus. Because of the correlation of A. hydrophila densities with such measures of water quality, this microorganism has been proposed as an indicator of the degree of nutrient loading or trophic state of surface waters (Rippey and Cabelli 1980). The finding of such correlations does not imply a causative or functional relationship between water quality and A. hydrophila.

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[4] Total coliform median most probable number (MPN) must not exceed 70 per 100 ml, with not more than 10% of samples exceeding 230 per 100 ml, in order for shellfish beds to be approved for harvest (U.S. Public Health Service 1965).

In summary, bacterial quality of estuarine waters may be affected by increased direct discharge of coliforms from disturbed land sources. Physical and chemical conditions of drainage water appear to be related to densities of Aeromonas hydrophila, a fish pathogen. The significance of this relationship to agricultural development is not presently known.

WATER QUALITY OF RUNOFF FROM FOREST LANDS

Forest Land Ownership and Management

In pocosin regions, silviculture is practiced on lands owned by large timber industries, small individual landowners, and public agencies (state and national forests). Land ownership influences management practices which in turn can affect the quality of surface water runoff. Estimates of the amounts of forest land area under various forms of ownership in the Coastal Plain of North Carolina are given in Table 13.

Expanding national and world demand for wood products is placing increased pressure on southern forests for more intensive management (Campbell and Hughes 1981). Pocosins have certain desirable features for timber production because of their large, flat and comparatively uniform land areas; adequate subsurface soil moisture even in drought periods; good growth potential; and low erodibility (Campbell and Hughes 1980). Water management techniques developed through research in the last 10 to 15 years have enabled planting of loblolly pine (Pinus taeda) in areas formerly too wet for it to grow and have resulted in greatly improved tree growth. Logging operations have been facilitated by drainage, and the potential for damage to wet soils has been reduced (Hughes 1982).

Under forest industry management, the rotation period for pines is comparatively long (25-35 years) in pocosins. Field ditches and collector canals on corporate plantations lower the water table by 0.3-0.6 m (1-2 ft) and lessen seasonal water table fluctuations. The period of time that surface soil is saturated is reduced by one-half to two-thirds, and standing water is considerably decreased. Although the land is not sloped artificially, creation of

Table 13. Ownership of commercial forest land in the North Carolina Coastal Plain region (from N.C. Div. of Environ. Management 1979).

Ownership Category	Land Use, ha (ac)	Percent of Total Commercial Forest Land in the Coastal Plain
National forests	59,130 (146,000)	3
Forest industry	733,000 (1,810,000)	34
Private ownership[a]	1,391,600 (3,436,000)	64
Total	2,183,800 (5,392,000)	100

[a] Obtained by subtracting total of national forest and forest industry land from total commercial forest land.

raised beds provides well-drained "microsites" for seedlings and reduces the need for rapid drainage. Typical stand management over a rotation includes one or more thinnings, applications of phosphate fertilizer, an optional pruning, and control of competing vegetation by periodic burning, or by chemical or mechanical measures. Burning is limited to a few hours in a tract, usually carried out between December and March, in order to minimize damage to organic soils (J. Hughes, personal communication). Pond pine is the dominant species of pine found in many natural pocosins and has superior survival in wet soils, but loblolly pine is generally preferred for replanting at the present time because of its superior growth potential (R. Campbell, Weyerhaeuser Co., New Bern, NC, personal communication).

Because trees can withstand much longer periods of inundation than row crops, maximum surface water removal is important only in the first 2-3 years of growth. Water removal by transpiration increases with stand age and density. On some industrial land, maintenance of a sufficiently high water table in maturing forest stands may become a concern. This may be dealt with by installation of water control devices such as flashboard risers (Figure 26), restrictive culverts and outlets (Figure 27), and impoundments (Figure 28). In a large pocosin, water level may be "stairstepped" using these devices as part of a gravitational flow system from the higher pocosin center toward the edges. Pumping typically is not used except during harvest, when temporary portable pumps may be necessary to lower water level in the tract being harvested. Excess water is pumped into adjacent forest tracts (J. Hughes, personal communication).

Clearcutting, combined with artificial regeneration, has been the most widely practiced method of harvest by the forest industry in the lower Coastal Plain of North Carolina. Clearcutting is suited to cultivation of fast-growing species which are intolerant of competition from other trees (U.S. E.P.A. 1973). Clearcutting may be done over entire watersheds or in strips or patches. Logging by track or rubber-tired skidder is the usual procedure. Compared to alternative methods used in mountainous regions, skidding is less expensive but increases the potential for erosion and soil compaction (Dyrness 1972).

Water Quality

Forested land is the source of two-thirds of the water supply of the State of North Carolina and is vital in

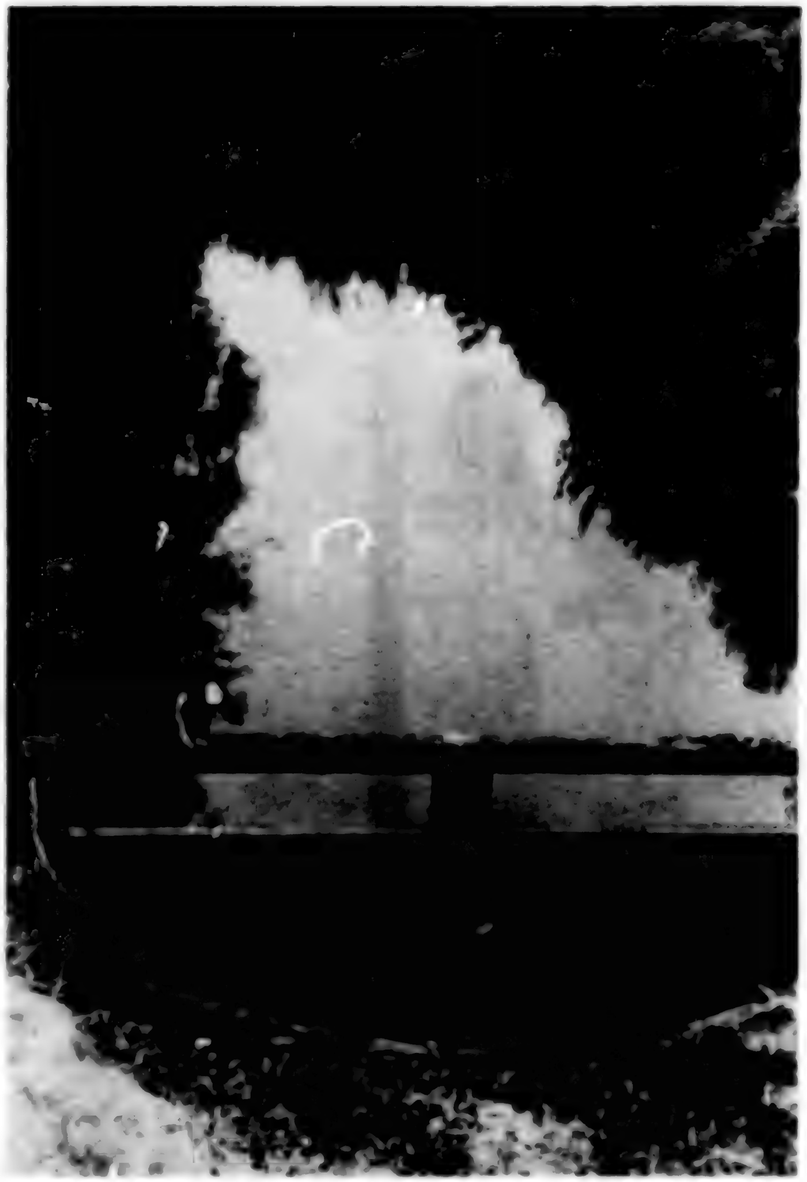

Figure 26. Flashboard riser used as a water control device at a canal intersection on forest industry pocosin land.

Figure 27. Restrictive vegetated drainage outlet on forest industry pocosin land.

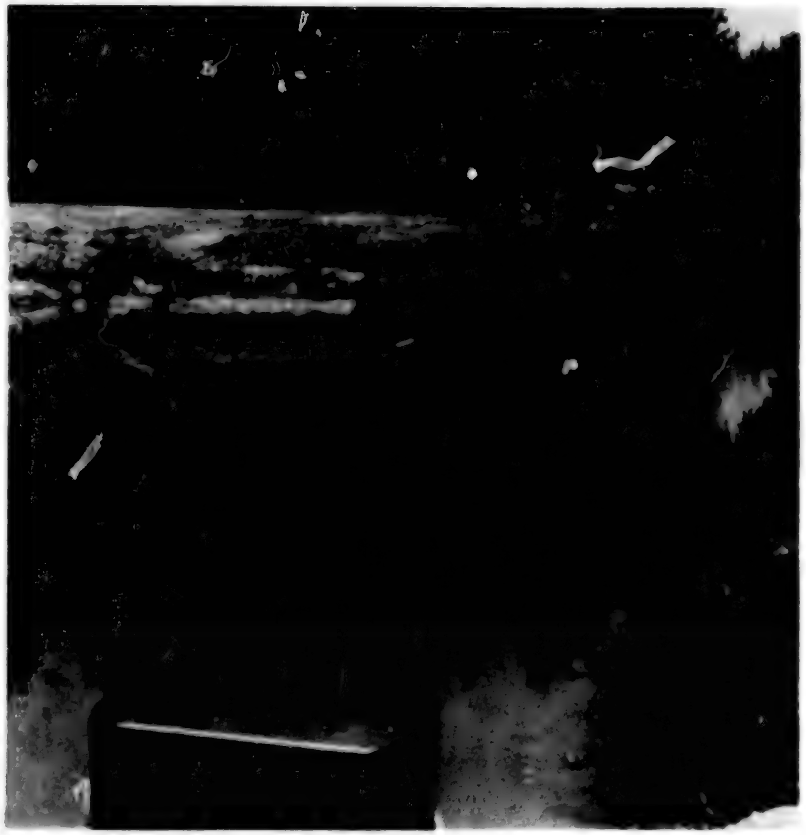

Figure 28. Impoundment ("helicopter pond") for water level management and fire protection on forest industry pocosin land.

maintaining surface water of high quality (N.C. Div. of Environ. Management 1979). Although silvicultural practices on commercial forest land appear to have less impact on water resources than those used for annual agricultural crops, there is little quantitative information on the relation between silvicultural practices and water pollution. Drainage, even from intensively managed forest land in pocosin areas, appears to result in rates of discharge that are more uniform over long time spans than those from agriculture. However, erosion from forest land has been studied less than that from agricultural cropland, and erosion rates are not as well known. Overall erosion from commercially managed forest land is estimated to contribute about 0.4 percent of total annual erosion to North Carolina; however, erosion per acre from disturbed forest land is estimated to be 7 times greater than that from undisturbed forest land (N.C. Div. of Environ. Management 1979).

Established, well-managed forest stands are erosion-resistant because of interception and absorbance of rainfall and consequent low runoff. Permanent and temporary access roads which are associated with commercial forestry, however, are a major source of erosion (U.S. E.P.A. 1973, Patric 1976, N.C. Div. of Environ. Management 1979, and others). Periodic disturbance of forests by harvesting activities results in large potential increases in runoff accompanied by erosion from exposed soils (U.S. E.P.A. 1973). The Weyerhaeuser Company reports that about 7-8 percent of its land area undergoes disturbance annually. Access roads constitute a permanent 3 percent of this disturbance with combined clearcutting and site preparation contributing another 4-5 percent. Of these disturbances, roads are reported to contribute the major portion of runoff and sedimentation (Hughes 1982). Attention to access roads and to the period of time between harvest and reestablishment of the forest is important in control of erosion and water pollution from commercial forests.

The major water pollutants from silvicultural activities are eroded sediment, organic debris, nutrients and chemicals, and thermal pollution. Of these, eroded sediment is the principal pollutant, and it also enhances chemical and organic matter pollution by its role as a carrier (Corbett et al. 1978). Reviews by Corbett et al. (1978) and Sopper (1975) summarize much of the published information on water quality.

Sediment. Sediment erosion originates principally from roads, with additional contributions from log skidding during harvest and from stream or channel banks (U.S. E.P.A. 1973). In North Carolina, an average of 1.7 metric ton/ha/yr (0.75 ton/ac/yr) of sediment is eroded from private and industry-owned forestland (N.C. Div. of Environ. Management 1979). Although this amount is much less than the 11-34 metric ton/ha/yr (5-15 ton/ ac/yr) or more which is typical of soil erosion from agricultural land, it can lead to serious local problems of turbidity and light reduction, filling of fish spawning beds, and reductions in populations of organisms which form the base of aquatic food webs (Corbett et al. 1978). A comparison of the sediment yield from bare and seeded forest roads (Wollum 1962) illustrates the potential magnitude of the problem. Sediment yield from a bare road cut on forest land in Oregon decreased from 23,270 kg/ha (10.4 ton/ac) to 7,728 kg/ha (3.4 ton/ac) the first year after seeding and decreased further to 4,232 kg/ha (1.9 tons/ac) the second year after seeding. This represents a reduction in sediment yield of 67 percent during the first year and 82 percent during the second year. Fredriksen (1970) showed that soil exposure on roads can be more important to sediment pollution than the area of land undergoing clearcutting. When 100 percent of a steeply sloping area without roads was clearcut, sediment yield was three times that of a non-harvested control area; but when 25 percent of an equal area containing roads was clearcut in patches, the sediment yield was about 85 times that of the control area (Table 14). However, similar comparisons for flat coastal plain areas typified by soils with high levels of organic matter are lacking.

The amount of sediment lost through erosion depends on soil type, topography, vegetative cover and management, and precipitation. Prediction of erosion losses from North Carolina forest land may be attempted with the aid of the Universal Soil Loss Equation (USLE) (U.S. Soil Cons. Serv. 1981). Values for the cover-management factor, C, developed by Dissmeyer and Foster (1981) should be substituted for those given in "C Values of Forest Land," pp. 62-63, U.S. Soil Cons. Serv. (1981). Estimation of C values is based on evaluation of several subfactors including the amount of bare soil, canopy cover, soil reconsolidation, soil organic content, and fine roots (Dissmeyer and Foster 1981).

Value of the USLE for predicting sediment erosion is limited. Erodibility values (the K factor) have not been determined by the Soil Conservation Service for many highly organic North Carolina soils (U.S. Soil Cons. Serv. 1981). Further information is needed to develop the relationship between the USLE and quantities of discharged pollutants. The USLE predicts soil losses from fields and not actual sediment yields to streams, although conversion factors can be developed to compensate for this. Also, the actual amounts of pollutants (nutrients, chemicals) associated with various soil types and other factors and capable of being carried on sediment particles have generally not been determined.

Organic matter. Organic matter and debris carried in runoff from undisturbed forests serve as an energy source and provide habitat for aquatic organisms. Excesses of organic loading from silvicultural operations, however, can cause downstream problems. Organic debris from logging ranges from green logs, stumps, and treetops which obstruct channels to fine particulate matter and soluble humic substances which may settle in spawning beds and deplete dissolved oxygen, thus interfering with the needs of aquatic organisms (U.S. E.P.A. 1973, N.C. Div. of Environ. Management 1979).

Table 14. Effects of clearcutting and roads on sediment yield from a forested area (from Fredriksen 1970).

Silvicultural Practice	Roads[a], km (mi)	% of Area Harvested	Sediment Loss, metric tons/km^2/yr (tons/mi^2/yr)
Control (no harvest)	0 (0)	0	32.5 (93)
Clearcut	0 (0)	100	107 (307)
Clearcut in patches	2.65 (1.65)	25	2,794 (7,982)

[a] Roads met standards for all-weather roads, including culverts, crossdrains, and crushed rock surface, established by the U.S. Forest Service.

Water temperature. Removal of shade cover over stream and drainage channels often results in elevated stream temperatures (U.S. E.P.A. 1973). While temperature maxima can increase by as much as 8-12° C (14-21°F) with complete removal of vegetation from a watershed (Corbett et al. 1978), increases of 2-5° C (4-10° F) are the more common situation (N.C. Div. of Environ. Management 1979). Increases in stream temperature decrease the amount of dissolved oxygen available to aquatic organisms, since the saturation concentration of oxygen is lowered with increasing water temperature and at the same time oxygen-demanding bacterial decomposition processes accelerate. Algal species composition in warmed waters tends to shift from diatoms toward blue-green algae, some of which fix their own nitrogen, resulting in algal blooms and potential eutrophication (Corbett et al. 1978, U.S. E.P.A. 1973).

Impacts of increased stream temperatures on fish are several. Because some fish species require different temperatures at different stages of their life cycle, temperature changes may affect fish development and migration patterns. Species composition may shift toward less desirable fish which are more tolerant of warm temperatures. In addition, populations of fish pathogens tend to increase (Corbett et al. 1978, U.S. E.P.A. 1973). Increased densities of *Aeromonas hydrophila* and resultant outbreaks of red sore disease have been reported in thermally polluted reservoirs (Esch and Hazen 1980). Leaving vegetated buffer strips from 12 to 30 m (40 to 100 feet) wide has been recommended for maintaining lower stream temperatures (Corbett et al. 1978).

Nutrients. Results of studies of nutrient transport from selected managed forests were summarized by Sopper (1975). Nitrate concentrations in runoff ranged from 0.002-0.013 mg N/l in undisturbed hardwoods to 0.4-28 mg N/l in clearcut areas (Table 15). Phosphate concentrations were found to be 0.02-0.04 mg P/l in runoff from a forested area and 0.04-0.07 mg P/l from a clearcut area in West Virginia (Table 15). Since nutrient losses may be proportional to erosive forces on steep land, major concern has focused on commercial forestry practices in mountain areas. There is a general belief that nutrient losses from Coastal Plain forests are so low as to be negligible (N.C. Div. of Environ. Management 1979). However, data supporting this idea, including comparisons among various stages of rotation and relative amounts of disturbance, are largely lacking.

Nutrient concentrations in runoff vary with soil type and geologic substrate, terrain, and specific management practices. All of these factors interact so that attempts to

Table 15. Nutrient concentrations in runoff from selected managed forest lands (data tabulated from Sopper 1975).

Location	Management Practices	Nutrient, mg/l Nitrate (as N)	 Phosphate (as P)	Source
White Mountains, N.H.	Clearcut	28	-	Pierce et al. 1972
Hubbard Brooks, N.H.	Strip cuts, 25 m wide on 35-ha area, cut at 2-yr. intervals:	2.3 (max. for growing season) 7.2 (max. for dormant season)	-	Hornbeck et al. 1974
	Clearcut:	>26 (max.)	-	
W. Va.	Forested area:	0.32 (growing season) 0.10 (dormant season)	0.04 (growing season) 0.02 (dormant season)	Aubertin and Patric 1972
	Clearcut area:	0.18 (growing season) 0.49 (dormant season)	0.07 (growing season) 0.04 (dormant season)	
Leading Ridge, Pa.	Control area:	0.07	-	Lynch et al. 1973
	Partial cut, herbicide treatment:	0.07	-	
Coweeta, N.C.	Undisturbed hardwoods:	0.002 - 0.013	-	Johnson and Swank 1973;
	Hardwood converted to pine:	0.25	-	Douglass and Swank 1974
Needle Branch, Ore.	Before logging:	0.12, 0.19 in successive years	-	Fredriksen et al. 1971
	After clearcut and slash burn:	0.44, 0.43		
	25% partial clearcut:	No increase over before logging	-	

isolate the effects of individual factors are difficult. On a watershed in the Hubbard Brook ecosystem in New Hampshire, clearcutting followed by three summers of herbicide treatment increased nitrate levels in stream water from 2 mg/l to 80 mg/l (Likens et al. 1970). Repeated extensive application of herbicides is not general in forestry, and clearcutting alone would not be likely to result in nitrate contamination of this magnitude because of rapid uptake by growth of weeds and brush (Sopper 1975). Strip clearcutting and use of buffer strips along drainage channels can decrease nutrient losses (Sopper 1975, Corbett et al. 1978). Drift from aerial spraying or direct application of fertilizers and fire retardants to streams and drainage canals can lead to water contamination (U.S. E.P.A. 1973).

Nutrients in drainage from silvicultural areas can originate from erosion of natural soil nutrients or from added fertilizers. In coastal plain forests, a general soil phosphorus deficiency often necessitates phosphorus fertilization, and additions of both nitrogen and phosphorus may increase tree growth (U.S. E.P.A. 1973). Fire retardants such as diammonium phosphate are also often applied. Applications may be on the surface of the ground before planting sometimes followed by aerial spraying every five to ten years (N.C. Div. of Environ. Management 1979). The poor phosphorus retention capacity of highly organic North Carolina soils has been demonstrated in agricultural studies (Fox and Kamprath 1971, Skaggs et al. 1980), although measurements of phosphorus or nitrogen losses from managed forests in pocosin areas are not available.

Pesticides. Losses of productivity to insects and disease in commercial forests are far greater than losses to fire; thus chemical control is regarded as important by the forest industry (U.S. E.P.A. 1973). Use of pesticides by private individual and industrial landowners is undocumented because private industry is not required to report pesticide use. In addition, lack of information on the fate of pesticides and the amounts carried in runoff make the extent of the problem uncertain. The current approach is that the benefits of pesticide use outweigh the risks involved, which are assumed to be small. Caution in the use of pesticides on forests has been recommended, since profuse application of pesticides to the complex forest ecosystem may result in unknown basic ecosystem alterations (U.S. E.P.A. 1973). Depending on the mode of application, avoidance of pesticide application in buffer strips of varying widths along drainage courses has been proposed as effective in reducing water contamination (U.S. E.P.A. 1973).

Timber Sales Contracts

Harvest on both industrial and privately owned lands is largely carried out by private contractors. However, the terms of performance guarantees of contracts with private harvesters vary from verbal "handshake" agreements with little performance control to detailed written contracts accompanied by performance bonds. The latter type of contract is likely to provide the greatest degree of water quality protection (N.C. Div. of Environ. Management 1979). Contracts by timber corporations generally contain fairly strict water quality guidelines while contracts by small private landowners are less formal. Often, small landowners are mainly interested in immediate income from timber sales and are not primarily concerned with regeneration and investment in continued harvests (C. Franklin, N.C. State University School of Forest Resources, personal communication). Most (64 percent) commercial forest land area in the Coastal plain of North Carolina is owned by private individuals (Table 13). Although there are no data on water quality with relation to forest ownership, the potential for problems appears to be greater on small, privately owned lands. Harvest agreements between small landowners and timber contractors may be an area where landowner education and incentive or regulatory measures for controlling water pollution can be effective (U.S. E.P.A. 1973).

EFFECTS OF WETLANDS ON DRAINAGE WATER

Comparisons of water quality in watersheds with and without large areas of wetlands have shown that wetlands have significant effects on hydrology and water quality. Floodplain swamps serve as water storage areas, tending to attentuate peak discharges in floods (Mitsch et al. 1977) and acting as sinks for sediment suspended in water (Mitsch et al. 1977, Brinson et al. 1981b). Some wetlands, because of slow sheet flow and increased contact time of water and soil, tend to alter the forms and amounts of nutrients which enter them (Kuenzler et al. 1977, Brinson et al. 1981a, and many others).

In practice, the effects of particular wetlands on hydrology and water chemistry will depend on the hydrologic type of the wetland (for example, whether it is a seepage or a flow-through system), soil characteristics, overall nutrient inputs, vegetation, and climatic factors. Florida cypress domes, whose output is almost entirely seepage to groundwater with very little surface outflow, tend to serve as effective nutrient filters; water from the domes percolates slowly through soil which removes materials before the water reaches the aquifer (Odum and Ewel 1978). Some peat soils possess high cation exchange and adsorption capacities, which may be partially responsible for high nutrient removal rates (Richardson et al. 1976). However, North Carolina peat from a pocosin area has been shown to have very low cation exchange capacity (Snyder 1978).

The specific function of pocosin wetlands in maintenance of water quality has been difficult to study and is still poorly understood. Inputs to pocosins are mainly from rainfall, which is relatively nutrient-poor. Hydrologic output from natural pocosins is generally by slow sheet flow through the surficial soil and root mat (Heath 1975; see Characteristics of Natural Pocosins: Natural Hydrology in this document). Brinson et al. (1980) found that concentrations of filterable reactive phosphorus and nitrate were lower in coastal plain peat-draining streams, which originate in pocosin areas, than in coastal plain swamp-draining streams, whose water derives mainly from upland mineral soils (0.005-0.017 mg P/l and 0.10-0.23 mg N/l for peat-draining streams; 0.027-0.028 mg P/l and 0.22-0.44 mg N/l in unaltered swamp-draining streams). These low nutrient exports from natural pocosins may be a result of several factors including the external factor of low nutrient inputs and inherent pocosin conditions such as anaerobic soils, vegetational uptake, residence time, lack of disturbance, and others. The relative importance of each of these factors is presently unevaluated.

Pocosin wetlands are different in hydrology and vegetation from swamp forests and marshes (see Characteristics of Natural Pocosins: Associated Ecosystems). Swamp forests and marshes adjacent to pocosins have been considered for use as buffer zones for treatment of agricultural runoff (Kirby-Smith and Barber 1979). The nutrient processing functions of these wetlands, in contrast to pocosins, have been extensively studied. Thus, wetland types must be evaluated on an individual basis, and the annual budget of each nutrient must be determined for the wetland before judgments can be made about filtering or buffering capacity of a particular area (Mitsch et al. 1977).

Nutrient Processing Capacities of Wetlands

Certain wetlands appear to have considerable nutrient processing capacity. Attention has focused on nitrogen and phosphorus because of the importance of these major plant nutrients as factors in downstream eutrophication. Effects of wetlands on forms of nitrogen appear to be more universal than effects on phosphorus, which depend on soil and sediment substrates, vegetation life cycles, hydrologic seasonality, and climate.

The anaerobic zone typically present in wetlands affects nitrogen present in surface water by providing a site for denitrification of nitrate to gaseous forms of nitrogen which then escape to the atmosphere. In many wetlands, a large proportion of nitrogen is lost to the atmosphere in this way. Large amounts of organic matter, also typical of wetlands, provide an energy source for this microbially mediated process. Patrick et al. (1976) described transformations of nitrogen which occur in flooded soils, demonstrating that the active site of microbial denitrification is in the soil or at the soil-water interface, rather than in floodwater itself. Ammonium present in floodwaters and flooded soil underwent nitrification in aerobic layers to NO_3^{-1} and subsequent denitrification in the anaerobic layers to gaseous N_2 and N_2O. Added nitrate disappeared rapidly as it was denitrified in the anaerobic zone. Brinson et al. (1981a) showed rapid disappearance of nitrate added to swamp surface water in a North Carolina alluvial swamp on the Tar River. Consistently low concentrations of nitrate were maintained in surface water, even with weekly nitrate additions, but ammonium additions led to high accumulations in surface and subsurface waters and sediments. These high accumulations were largely depleted in drydown periods during the growing season, when the ammonium reverted to nitrate and the nitrate was subsequently denitrified. Mitsch et al. (1977) found lower nitrate concentrations in the surface water of an Illinois cypress-tupelo swamp than in adjacent river water, although ammonium and total nitrogen concentrations were higher in the swamp than in the river. Dierberg and Brezonik (1978) found that 83-95% of combined nitrate and nitrite was removed from sewage as it was passed through swamp soil cores; on the other hand, ammonium recovered from the soil leachate increased over the initial levels in the sewage, which could have resulted from reduction of nitrate as well as mineralization of organic nitrogen compounds and the low cation exchange capacity of this soil.

In the intensively agricultural upper Coastal Plain of eastern North Carolina, Kuenzler et al. (1977) found that nitrate concentrations in small, unchannelized streams associated with floodplain wetlands were much lower than nitrate concentrations in channelized streams, whose flow has been largely diverted from contact with wetlands. Ammonium concentrations, however, were not significantly different in the two types of streams.

In a comparison of watersheds from the temperate zone, Kuenzler et al. (1977) found that a "salient feature of wetlands" was their "scant exports of nitrate." Watersheds with extensive wetlands had nitrate fluxes generally less than 50 kg/km^2/yr (0.4 lb/ac/yr), while those without extensive wetlands generally had exports of more than 150 kg/km^2/yr (1.3 lb/ac/yr).

In contrast to nitrogen, the phosphorus cycle includes no atmospheric pathway; there is no ready "escape valve" mechanism which can remove phosphorus from the system. Thus, phosphorus may potentially represent a larger problem than nitrogen in nutrient processing of runoff water. Sloey et al. (1978), in a review of nutrient assimilation by wetlands, state that "permanent" removal of phosphorus can only occur when insoluble phosphorus compounds enter the substrate; however, the substrate can be a source as well as a sink for phosphorus under different conditions.

Transfer of phosphorus from sediments to overlying waters depends on O_2 concentrations at the sediment-water interface. Concentrations of phosphorus in Pamlico River Estuary sediments were found to be significantly lower under low oxygen conditions (Hobbie 1970b). Higher concentrations of phosphorus were found in Pamlico bottom water in summer, attributable to the transformation of insoluble ferric phosphate in sediments to soluble ferrous phosphate under low redox potential (Hobbie 1970b). Phosphorus is less likely to go into solution from sediments at pH = 5-7 than at higher or lower pH (Kramer et al. 1972, cited in Sloey et al. 1978).

Seasonal conditions affect phosphorus retention and release by wetlands. Kibby (1978) states that wetlands tend to be very "leaky" of phosphorus. For example, phosphorus which is taken up by marsh plants can be released from dead plants when decomposition occurs at the end of the growing season; 22% of the P uptake was released from dead plants in a Carex community (Kibby 1978); 58% of P taken up by a Scirpus community was released later (Klopatek 1978). Simpson et al. (1978) estimated that 95% of the phosphorus in living tissues of aquatic plants in a freshwater tidal marsh was lost after frost and decomposition. Seasonal flushing can also wash out large quantities of phosphorus which have previously been detained by the wetland system. For example, during dry periods aeration increases the rate of decomposition of organic matter and consequent mineralization of P. Flooding which occurs prior to the next growing season (when P would again be taken up) may carry a large "slug" of phosphorus to receiving waters such as an estuary (Sloey et al. 1978). Brillion Marsh, a Wisconsin cattail marsh which has been receiving sewage and agricultural runoff since 1923, showed retention of about one-third of the large annual input of P in the sediments of the influent stream channel by "permanent" storage in organic muck (Spangler et al. 1977). Apparently, this Wisconsin muck has better P adsorption capacity than organic soils of eastern North Carolina, which have been shown to lose P readily to drainage water (Fox and Kamprath 1971, Skaggs et al. 1980). Sloey et al. (1978) conclude that wetlands probably function as partial sinks for P during some seasons and as partial sources at others.

Forested wetlands associated with natural streams have been shown by several studies to detain and assimilate phosphorus under some circumstances. Kuenzler et al. (1977) found that waters of unchannelized eastern North Carolina streams with large related areas of wetlands had lower concentrations of phosphorus (0.01-0.03 mg/l of particulate P) than the waters of channelized streams (0.03-0.11 mg/l particulate P), which bypass their original connections with bottomland forests. Channelized streams contained about twice the concentrations of filterable reactive phosphorus as unaltered streams. There are indications that loss of stream contact with swamp forests through channelization in the Chowan River watershed may be an important factor in increased eutrophication of the Chowan River (Craig and Kuenzler 1982). An approximate 50% reduction in phosphorus concentration was found in the months of January through April for river water passing through the Santee Swamp in South Carolina. Kitchens et al. (1975) suggest that the swamp may be a biological sink for phosphorus through uptake by aquatic plants during this 4-month period. Brinson et al. (1981a) found that phosphate accumulated in the surface water, subsurface water, and sediments in chambers with weekly experimental additions of phosphate and municipal sewage effluent in the Tar River (North Carolina) alluvial swamp. These phosphate levels were not depleted during the ten-month duration of the study. Mitsch (1979) reported that a cypress-tupelo swamp in Illinois was a significant sink for phosphorus. The associated Cache River contributed ten times the amount of phosphorus to the swamp as was discharged to the river, yielding 15.7 g/m^2/yr of phosphorus in deposition to sediments in the swamp. Nessel (1978), reporting on a study of sewage effluent application to a Florida cypress strand, found that about half the annual phosphorus input was retained in this strand (a "flow-through" system), mainly in the sediments. Brinson et al. (1981b) cite a range of annual phosphorus deposition rates in floodplains from 1.7 to 30 kg/ha, although documentation of possible erosion which may involve phosphorus exports from such floodplains is incomplete.

Experimental Wastewater Application to Wetlands

Richardson et al. (1976) studied the effects of nutrient additions (simulated sewage effluent) on a peat wetland in Michigan. The slow rate of subsurface water movement, high sorption capacity of this peat, denitrification taking place in the soil, and increased plant nutrient uptake led to the conclusion that the peatland had potential as a biological filter for nutrients, although long-term applications and effects were uncertain. Other workers (Farnham 1974, Stanlick 1976) have reported on the effectiveness of artificial peat/sand filter beds in small sewage treatment situations. One such system is reported to have removed as much as 99% of the phosphorus and 85% of the nitrogen, as well as reducing coliforms nearly 100%, from sewage from a campground (Stanlick 1976).

Turner et al. (1976) reported the results of experimental application of wastewater from a menhaden processing plant to a Louisiana freshwater marsh. This method was estimated to remove 58% of the organic carbon, 51% of the nitrogen and 53% of the phosphorus in the wastewater over the experimental period of eight months. The wastewater was applied by spraying at the top of a spoil bank which sloped into the marsh; groundwater nutrient concentrations were higher at the bottom of the slope than at the top, near the maximum U.S. Public Health Service limit for nitrate. Losses of nutrients by percolation to the groundwater and uptake by plants combined were less than 5%. Coliforms were 66% lower at the bottom of the slope and decreased further with distance from the slope, but exceeded state standards where the soil was saturated for long periods. The authors caution that groundwater contamination may become a problem and recommend a further long-term pilot study before application is tried on a large scale.

Some of the longest-term and most extensive studies of wetland application of wastewater have been performed on Florida cypress domes by Odum and Ewel and associates. The domes, which are wetlands lacking significant surface outflow, and their associated soils have shown to act as effective filters of nutrients in municipal sewage over several years of study. Nutrients in the groundwater under the domes have shown little difference from background levels, attributable to the organic sediments and hardpan layer underlying the swamps. Figure 29 illustrates the inputs and outputs of nitrogen and phosphorus in the domes. The large storages which are taking place in the domes are indicated to be mostly in the sediments and plant biomass (Dierberg and Brezonik 1978). The cypress domes exported about 3% of their annual phosphorus inputs to groundwater while a nearby cypress strand (with substantial surface outflow) used for municipal sewage effluent discharge exported approximately half its annual phosphorus input downstream from the strand (Dierberg and Brezonik 1978).

Wastewater applications can have a mixture of effects on wetlands themselves. Ewel (1978) reports that biomass of understory vegetation in four cypress domes receiving sewage increased substantially after additions were begun. The most immediate and obvious effect was the growth of a thick mat of small floating plants including duckweed (Lemna perpusilla, Spirodela oligorhiza) (Ewel 1976), which assimilated up to 2% of its biomass as phosphorus, taking up an excess of P over its requirements as "luxury uptake" (Ewel and Deghi 1978). Nessel (1978) reports that cypress growth rates increased substantially after sewage additions were begun in a nearby cypress strand (flow-through system). Mean basal area increments increased by about twice over former increments, and concentrations of phosphorus in most recent stem wood increments have been four to five times former concentrations.

On the other hand, growth of some species has been retarded and some species have been eliminated altogether from wetlands treated with wastewater. Water lily (Nymphaea odorata) and bladderwort (Utricularia sp.) decreased in sewage-treated cypress domes and there was evidence of decreased diversity and an increase in mosquito fern (Azolla caroliniana) and duckweed (Ewel 1976). Whigham and Simpson (1976) found that touch-me-not (Impatiens capensis) had been eliminated from a Delaware marsh receiving sewage applications while there was an increase in epibenthic algae. Increased duration of higher water levels in forested wetlands can detrimentally affect the survival of indigenous tree species (Teskey and Hinckley 1977).

Water quality in cypress domes themselves was substantially altered by additions of sewage (Dierberg and Brezonik 1978). Concentrations of nitrogen in surface water of domes receiving sewage were several times higher than in control domes. Ammonia made up a larger fraction and organic

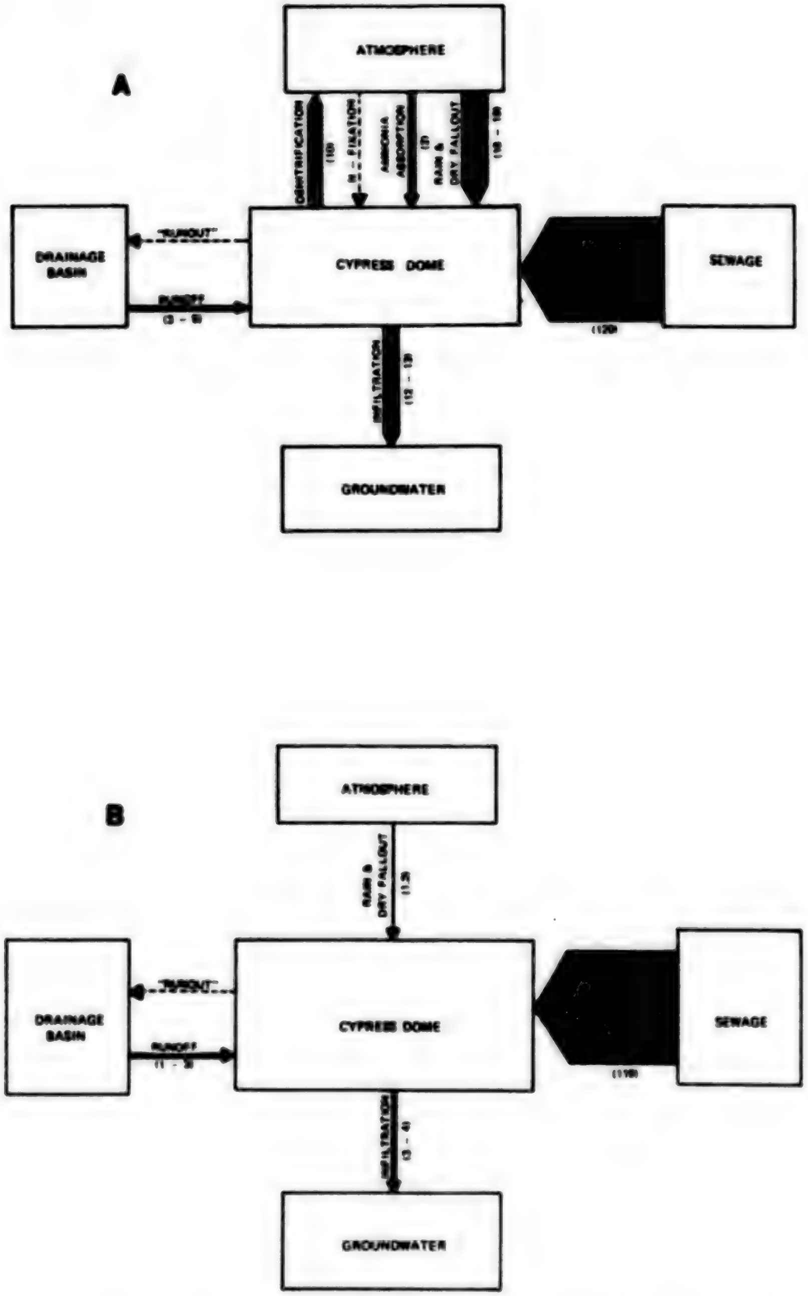

Figure 29. Major annual fluxes (kg/ha/yr) of total nitrogen (A) and total phosphorus (B) in cypress domes receiving sewage (Dierberg and Brezonik 1978).

forms of nitrogen were a smaller fraction of the total nitrogen in sewage domes compared to control domes. Concentrations of total phosphorus were 2-100 times higher in sewage dome water than in control dome water. Two cypress domes which received heavy fertilization with inorganic nutrients rather than sewage for several months had ammonia and total nitrogen levels similar to those in the sewage domes. The authors suggest oxidation pond treatment of sewage to reduce total N before application to cypress domes but report that this treatment would not affect phosphorus.

SUMMARY AND CONCLUSIONS

Hydrologic and Water Quality Research in Pocosin Areas

Research data from which accurate conclusions can be drawn about the hydrologic and water quality impacts of large-scale agricultural or forestry development of pocosin areas are presently inadequate. Effects on hydrology have been difficult to determine because the lack of a topographic gradient and the small number of well-defined streams in the Tidewater region have largely prevented stream gaging which would have supplied background information.

Long-term records of water quality are absent. A limited program of water quality monitoring for the purpose of classification of waters was begun by the N.C. Division of Environmental Management in the mid-1950's, and was expanded to the current more comprehensive program in the early 1960's. Even at the scale of the present program, limited funds prevent a sampling frequency at many stations at less than quarterly intervals. Numerous fish kills that occur in estuaries, especially in summer, are investigated routinely by the Division of Environmental Management. Most of the time, these kills can be assigned to one of three major groups: man-caused; caused by naturally occurring common phenomena (stratification and deoxygenation); or caused by uncommon natural phenomena (such as disease). However, the ultimate causative factor (such as the specific source of pollution) is often untraceable. Although the judgment of experienced observers is that estuarine impacts of agricultural drainage and development are comparable to those from other sources, such as upstream dams and industrial plants, this judgment is very difficult to document (Barry Adams, N.C. Division of Environmental Management, Washington, NC, personal communication).

Comparatively few studies have attempted to relate agricultural and silvicultural land use to water quality.

These studies include the report by Skaggs et al. (1980) on measurements in field-edge drainage from six sites on First Colony Farms in Tyrrell County; a study of water quality in streams and ditches draining from the Open Grounds Farm area in Carteret County by Kirby-Smith and Barber (1979); studies by Gambrell et al. (1975a and b) and Gilliam et al. (1978) evaluating nitrogen losses in drainage; effects of freshwater discharges on fish nursery areas in Rose Bay by Pate and Jones (1980) and Jones and Sholar (1981); a recent report (1982) by the N.C. Division of Environmental Management using literature estimates of agricultural and point-source nutrient discharges to calculate relative nutrient loadings into the Chowan River; and a report in preparation by Craig and Kuenzler using a mass-balance approach to estimate Chowan River nutrient loadings. In addition, studies of quality of drainage from silviculture have been conducted by timber corporations, but data from these studies are presently incomplete or available only for internal distribution (J. Hughes, personal communication; D. Duncan, International Paper Co., Bainbridge, GA, personal communication). Data have been collected, but not compiled, by the N.C. Division of Environmental Management for water quality in the Albemarle-Pamlico region.

The difficult problem of separating the effects of non-point sources of pollution from other sources has been addressed in studies conducted on the Chowan River Basin because of serious recurring blue-green algal blooms. Some of the results of the Chowan studies may be applicable to other areas adjacent to estuaries. Estimates from the Chowan River Water Quality Management Plan indicate that agricultural land is the source of 44% of the phosphorus loading of the Chowan River, while combined point sources contribute 35%; the report recommends reductions of 30-40% in phosphorus loadings from the basin (N.C. Div. of Envir. Management 1982). A second study of Chowan Basin nutrient inputs by Craig and Kuenzler (1982) cites agricultural land use as the source of 72% of phosphorus loadings to the Chowan (point sources constitute 6%) and suggests that drainage improvements, such as channelization, contribute to high P loading by short-circuiting drainage water contact with wetland forest filter areas. Recommendations for management in the basin differ somewhat between the two studies. The Division of Environmental Management study recommends that reductions of phosphorus from point sources would be sufficient to lower P loadings in dry years, while in wet years reductions from both point and non-point sources would need to be implemented. Craig and Kuenzler, on the other hand, point out that reductions of point-source phosphorus may be cost-ineffective in improving water quality because of their findings that these sources contribute a relatively insignificant amount of phosphorus to the river.

Attention has been focused on the Chowan River because of an obvious visible problem. Problems may be developing in other estuarine areas which are not yet as noticeable. The Chowan studies highlight the substantial cumulative impacts of numerous small nutrient inputs, relatively insignificant in themselves, as well as the large overall contribution of agricultural sources. The proximity and hydrologic relationship of the Chowan to Albemarle Sound and the entire estuarine system may mean that the kinds of management practices recommended for the Chowan basin should reasonably be considered for the Tidewater region as a whole.

Swamp Forests as Filters

Purification of runoff water from developed pocosin areas by allowing pumped discharge to flow through "natural filters" such as swamp forests and coastal marshes before reaching estuaries has been proposed as a water management strategy for large-scale agricultural development (Kirby-Smith and Barber 1979, S. Barnes, personal communication). Natural filter areas are expected to slow water velocity and remove sediments, nutrients, pesticides, and pathogens through a combination of physical deposition, chemical and microbial processes, and vascular plant uptake. Thus, pulses in runoff would be attenuated and water purified while soil and nutrients are retained in terrestrial ecosystem cycles.

Although the filtering capacity of many wetlands has been documented, the efficacy of specific wetlands in management of large quantities of agricultural runoff is largely unknown. In the process of agricultural drainage and development, the slow-rate hydrologic processes and treatment functions of one category of wetland (pocosins) are partially eliminated while hydrologic discharge and physical and chemical loads of runoff water are simultaneously increased by land disturbance and chemical additives. Demands may then be placed on the hydrologic and treatment capacities of another type of wetland, swamp forests, to perform many of the functions of pocosins that were bypassed by development. The pressures on swamp forests, which previously were subjected to natural, more uniform flow rates, will undoubtedly be increased with inputs of agricultural drainage. The swamp forest will be expected to accommodate the increased pulses of runoff which result from artificial drainage. Using a depth of 10 cm (4 in) of water on the wetland floor in order for substantial nutrient assimilation to take place (conditions typical of the Tar River Swamp; Brinson et al. 1981a), about 331 ha or slightly more than one square mile of wetland would be required to accommodate the quantity of water discharged in 10 hr of pumping by three pumps each operating at a typical capacity of 50,000 gallons per minute. Wetland areas smaller than this, in proportion to discharge rates, may not perform adequately as filter areas because of higher water levels or decreased residence time of water in the wetland, with consequent lower sediment deposition and nutrient assimilation rates. In addition, increased hydrologic and nutrient loading may affect swamp forests by decreasing survival and growth of native plant species and increasing growth of algae or duckweed. These kinds of changes may eventually affect the treatment functions of the wetland.

Implications of Water Quality Research

1. Studies have shown that pulses of runoff increase in magnitude when natural drainage mechanisms of pocosin areas are disrupted by ditching and clearing. These freshwater pulses are related to reductions in productivity of nursery areas in coastal creeks and marshes (Jones and Sholar 1981). The increased quantities of sediment, nutrients, and agricultural chemicals associated with high runoff discharges must also be considered potentially detrimental to oyster beds (Bahr and Lanier 1981).

2. Although they may be small in absolute magnitude compared to discharges from other areas, the percent increase in nitrogen in runoff from developed pocosin land is very high and may be hazardous in estuaries where caution has been advised regarding any further increases in nutrient loading.

3. Several factors indicate that phosphorus inputs from pocosin areas are worthy of major concern. Phosphorus is generally regarded as the primary limiting factor in the eutrophication of freshwater lakes. Some estuaries, Albemarle Sound in particular, can be regarded as essentially "freshwater lakes" because of their limited contact with marine inputs. An increase in the proportion of agricultural land in a watershed significantly increases phosphorus content of runoff; phosphorus concentrations in runoff from developed organic soils are especially high. Concentrations of this element can only be reduced by sediment fixation or plant uptake; however, the phosphorus fixation capacity of sediments is limited and may decrease with time so that eventually phosphorus is released from sediments to overlying waters. Plant uptake of phosphorus is seasonal and may be reversed when plants die. Thus, substantial reductions of phosphorus contributions at their source appear to be the major reliable way of controlling eventual phosphorus discharge to estuaries.

4. High nutrient and organic matter conditions in runoff water are related to the survival and growth of pathogenic microorganisms which cause red sore disease of fish. The sources and survival of coliforms in organic soils are enigmatic. If found in shellfish growing waters, high numbers of coliforms will result in these areas being closed to harvest.

5. Nitrate levels in water entering wetland filter areas are generally substantially lowered through denitrification in the soil-water system whereby N_2 and N_2O gases are lost to the atmosphere. Effects on other forms of nitrogen are less certain and more variable.

6. Contact with wetland soils may reduce phosphorus levels in drainage water. This occurs by storage of P in sediments or uptake into plant biomass; unlike nitrogen, phosphorus is not lost from the soil/water system. Capacity of wetlands for P removal before discharge into estuaries can be determined only after information is obtained on adsorption capacities of soils of local wetlands, timing of potential seasonal drydown, and timing and magnitude of flushing events.

7. It is important not to overload the nutrient and hydraulic capacity of wetlands; natural seasonal cycles of nutrient alteration mechanisms must be allowed to take place (Sloey et al. 1978). Both nitrogen and phosphorus appear to require an extended period of perhaps several days of contact with wetland soil or sediments for alteration. Rapid passage through a wetland of large quantities of runoff water will not remove suspended sediment and is probably not adequate to remove substantial quantities of nutrients; slow velocity appears to be essential. The preliminary nature of results of nutrient-enriched water applications to wetlands at present allows only an educated guess at the size of wetland area needed for effective treatment of agricultural runoff, but the necessity of extended contact of runoff water at shallow depths means that fairly large land areas may be required. Direct inputs of water to wetlands from local precipitation would increase the total volume of water and thus increase the land area required for effective treatment.

8. Agricultural runoff inputs may place less demand on nitrogen removal mechanisms of wetlands than sewage effluent because of generally lower concentrations of nitrate and ammonia in agricultural runoff water as compared to municipal sewage (Tables 8 and 9). On the other hand, phosphorus levels in agricultural runoff appear to be close to the range of those in municipal sewage (Tables 9 and 10), so that removal may be similar to results in sewage application studies.

9. Nutrient enrichment by wastewater has been shown to detrimentally affect surface water quality of wetlands by raising N and P concentrations, perhaps to undesirable levels. Plant species composition and relative density may also be affected by increased water depths and nutrient inputs.

10. Diking of wetland areas may be necessary in order to regulate large-scale out-flushing of nutrients (especially P) in floods. Control of water level inputs to wetlands may be needed to prevent untimely periods of drydown so that denitrification can proceed (Sloey et al. 1978).

CHAPTER 5. ALTERATIONS OF POCOSINS:
IMPACTS ON AQUATIC HABITAT

Increased pulses of freshwater carrying increased loads of sediment, nutrients, pesticides, and potentially increased concentrations of bacteria reach estuaries from developed pocosins and other areas. Much of the discharge takes place in relatively sensitive tributary creeks, secondary estuaries, and fringing marshes. The 10% of the North Carolina estuarine system which is in marshes forms the productive base for the entire system. Over 90% of North Carolina commercial fish harvests are of estuarine-dependent species (Street and McClees 1981). Since much of the productive marsh area is in close proximity to pocosins, concern about potential pollution from pocosin development is highly appropriate.

Coastal tributaries and marshes serve as habitat for juvenile stages of aquatic organisms; many are commercially important while others are integral parts of the food web on which the commercial species depend (Weinstein 1979, Pate and Jones 1981, Jones and Sholar 1981, Street and McClees 1981). As juveniles, many of these species are dependent on stable patterns of substrate and salinity. Brown shrimp, for example, are especially vulnerable to reduced salinities as illustrated by 20-40% lower catches when normal salinities of 10-15 ppt were lowered to 2.4 ppt by excessive rainfall in the nursery period (Street and McClees 1981). Reduced salinity in nursery areas is expected with high rainfall but nursery areas that receive canal drainage from pocosins have more extreme and rapid fluctuations of salinity than do unaltered nursery areas (Jones and Sholar 1981). Catches of juvenile brown shrimp, blue crab, southern flounder, spot, and menhaden were all reduced in nursery areas receiving canal drainage (Jones and Sholar 1981). Although reduced catches may be partly caused by movement out of the nursery area, it is thought that survival of juveniles that leave is lower because they are forced into areas that do not afford adequate food or cover.

Maintenance of proper salinity is highly important for oyster populations. Optimum salinity requirements for oysters vary with region; in Chesapeake Bay, these are 10-28 ppt, while in Louisiana they are 5-15 ppt. Studies summarized in reviews by Haven et al. (1978) for Chesapeake Bay and Van Sickle et al. (1976) for Barataria Basin, Louisiana, summarize information collected in these regions and indicate that oyster mortalities are correlated with reduced salinities. In North Carolina, production of oysters in the Pamlico River area has shrunk over the past 20 years to present "negligible" harvests. This reduction appears to be associated with lowered salinities (Street and McClees 1981).

While oysters are normally tolerant of turbid conditions, increased turbidity over natural levels can inhibit feeding activity and prolonged excess turbidity can reduce productivity of primary producers on which oysters depend. Increases in sedimentation over natural levels can smother oysters (Bahr and Lanier 1981).

Even when sublethal, the effects of pollutants in runoff can render oysters unfit for either natural predator or human consumption (Bahr and Lanier 1981). Runoff from agricultural land (both cropland and pasture and feedlot areas) can contain high numbers of coliforms (Skaggs et al. 1980). Although the connection between coliform bacteria, which are indicator organisms, and actual pathogens is not always direct, regulatory agencies do not attempt to distinguish between coliforms from agricultural origins or human waste sources. Federal regulations require that oyster beds where coliform counts exceed regulatory standards be closed to commercial shellfish harvest (U.S. Public Health Service 1965). States do not have the option of unilaterally relaxing coliform standards without jeopardizing their permits to engage in interstate commerce. Since illness has sometimes resulted from human ingestion of shellfish harvested from "approved" areas, the present trend in shellfish management is toward strict application of coliform standards in marginally contaminated areas, regardless of judgments about coliform origins (B.E. Kane, East Carolina Univ. Dep. of Envir. Health, personal communication).

Nutrient-enriched runoff may be contributing to the growth of certain pathogenic bacteria even though the bacteria might not originate from land sources. High phosphorus concentrations, for instance, have been correlated with increased density of Aeromonas hydrophila, which has been identified as the causative agent in outbreaks of red sore disease of fish in Albemarle Sound. In 1976, about 95 percent of the white perch population of Albemarle Sound succumbed in an outbreak of red sore disease; and approximately half of the commercial fish catch was discarded because of the effects of this disease (Esch and Hazen 1980). Outbreaks of the disease and extensive fish kills as well as deaths of several reptile species have been reported with increasing frequency in recent years in Florida and North and South Carolina (Esch and Hazen 1980). A. hydrophila has also been implicated as the causative agent in several cases of severe or fatal wound infections in humans following skin lacerations in marine and fresh waters (Hanson et al. 1977, Fulghum et al. 1978).

Densities of A. hydrophila were found to be significantly related to a number of water quality parameters, including coliform numbers, dissolved oxygen, turbidity, chorophyll a, sulfate, ammonia, total nitrogen, total organic carbon, and especially total phosphorus (Esch and Hazen 1980). These authors suggest that the water quality conditions cause increased stress on fish which combined with infections due to increased concentrations of the pathogen result in fish kills. Although the organism is reported to be associated with organic pollution, it appears to multiply in nutrient-rich wastewater rather than originating from human of livestock pollution (Fulghum et al. 1978). In one case of human infection, infection followed exposure to water from a ditch draining an agricultural and livestock holding area.

Phosphorus draining into the Chowan River has been implicated as the most important factor contributing to serious algal blooms which have become frequent in recent years (N.C. Div. of Envir. Management 1982). Since a major portion of the total phosphorus in drainage from organic soils is in the form of orthophosphate that is readily utilized by aquatic algae, increased use of organic soils for agriculture may be contributing significantly to the algal blooms. The N.C. Division of Environmental Management (1982) recommends 30-40% reduction of phosphorus from all sources in order to minimize future blooms in the Chowan River.

Concentrations of alachlor herbicide in drainage water from developed sites at First Colony Farms ranged from <0.0005 mg/l to 2.7 mg/l over a 3-year period with typical concentrations in the range of 0.001-0.05 mg/l (Skaggs et al. 1980). According to the investigators, movement of alachlor in surface runoff from First Colony lands appears not to be a significant source of water contamination because of "low concentrations" found in drainage water and the relatively low toxicity of this compound to fish. The maximum concentration of alachor in drainage water was about 40% of the LD_{50} for catfish (6.5 ppm). However, as this report states, other organisms may be more sensitive to alachlor and other pesticides may be more toxic. Insecticides are generally more toxic than herbicides, with the LD_{50} for fish ranging typically from 0.002 to 2 ppm. Filter feeders, such as clams and oysters, strain large amounts of water to obtain food and thus may ingest disproportionate amounts of pesticide (Leonard et al. 1976). Even if these amounts are sublethal, they may render the shellfish unfit for human consumption (Bahr and Lanier 1981).

CHAPTER 6. ALTERATION OF POCOSINS: PEAT MINING

The terms peat and organic soil (Histosol) are often used interchangeably. This leads to confusion, particularly when the reported distribution of Histosols (Figure 5) is very different from the reported distribution of peat (Figure 30). Histosols in North Carolina occupy 0.53 to 0.61 million ha (1.3-1.5 million ac) (Lee 1955, Leighty and Buol 1973, Lilly 1981a) while peat deposits are reported to occupy only 0.28 million ha (0.7 million ac) (Otte and Ingram 1980, Ingram and Otte 1981a).

Histosols are those soils which contain organic matter which is 12-18% organic carbon by weight, and which, excepting thin mineral layers, extends from the surface to one of the following:

1. A depth of 60 cm (24 in) or more if 75% or more of the volume is fibric sphagnum moss or if the bulk density is less than 0.1 g/cc (0.6 lbs/cu ft);
2. A depth of 40 cm (16 in) if the organic soil material is saturated with water for long periods (6 months) or is artificially drained, and the organic material has a bulk density of 0.1 g/cc (0.6 lbs/cu ft) or more;
3. A depth of 10 cm (4 in) or less above a lithic or paralithic contact, provided the thickness of the organic soil material is more than twice that of mineral material above the contact;
4. Any depth if the organic material rests on fragmental material (gravel, stones, or cobbles) in which the interstices are filled or partly filled with organic materials or rest on a lithic or paralithic contact.

More complete definitions can be found elsewhere (McKinzie 1974 , Soil Survey Staff 1975, Buol et al. 1980). Histosols are divided into four suborders on the basis of water saturation and decomposition of organic matter. Essentially all Histosols in North Carolina belong to the suborder Saprist and the great group Medisaprist (Lilly 1981a). Such soils contain less than 1/3 recognizable fibers by volume, have no significant humilluvic horizons, and have a mean annual temperature above 8°C (46°F) with winter and summer means differing by at least 5°C (9°F) (Soil Survey Staff 1975).

North Carolina peatlands represent only a fraction of all organic soils in the state, but the criteria used by Otte and Ingram (1980) to delineate peatlands are not clear. Virtually all soils mapped as peat by Otte and Ingram (1980) had organic layers at least 60 cm (24 in) deep. The soil series included are: Dare, Dorovan, Pungo, Mattamuskeet, Pamlico, Belhaven, Scuppernong and Ponzer.

The names and locations of the major North Carolina peat deposits exclusive of Carolina Bays are given in Figure 30. The extent of peat deposits is variable (Table 16), but the largest areas in descending order of size are the Albemarle-Pamlico Peninsula, the Great Dismal Swamp, Roanoke-Chowan River floodplains, and the Croatan National Forest. For more information see Otte and Ingram (1980), Ingram and Otte (1981a, b, c), and Otte (1981).

In the Coastal Plain of North Carolina, peat deposits may occur in any of four geological systems: coastal marshes, river floodplains, blocked drainage systems (often called broad upland flats or interstream divides), and Carolina bays (Otte 1981). Blocked drainages and Carolina bays account for an overwhelming majority of the surveyed peat in North Carolina (Table 16), but estimates of peat resources in coastal marshes are not available. Peat formation in blocked drainages and Carolina bays started 10,000-12,000 years ago when the sea level was 25 m (82 ft) below present (Otte 1981). Peat formation has continued until recently when artificial drainage precluded further peat development (Otte 1981). Due to their large size, peat deposits in blocked drainages are the areas being developed for peat mining. The Albemarle-Pamlico (Alligator River) deposit is the largest single deposit in the state. Five of the six peat mining permit requests either issued or under consideration by the North Carolina Department of Natural Resources and Community Development concern this deposit (Peat Mining Task Force 1981; Steve Benton, North Carolina Coastal Resources Commission, Raleigh, personal communication).

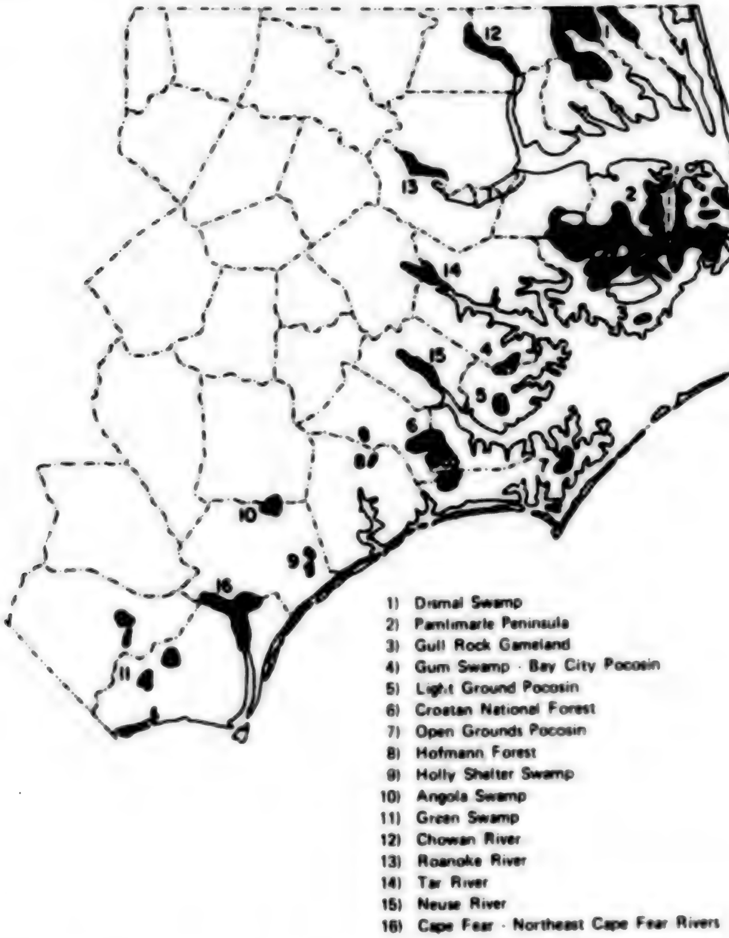

Figure 30. Location of peat in the coastal plain of North Carolina (from Otte and Ingram 1980).

The peat soils of North Carolina have several interesting attributes. Usually, the organic horizon is broken into two distinct layers. The lower layer, located directly above the mineral soil interface, is brown, decomposed fibrous peat derived from Atlantic white cedar leaves, plus stem fragments and seeds of many rushes, grass-like plants and various floating aquatic species (Ingram and Otte 1981a). Geologically, it is usually located at the bottom of infilled stream channels where peat deposition first occurred (Ingram and Otte 1981a). This layer can be up to 1.4 m (55 in) thick but is usually thinner and on average buried at a depth of 1.2 m (47 in). The upper layer, within 1.2 m (47 in) of the surface, is a black, fine-grained, highly decomposed, hemic to sapric peat. It lies directly over fibrous peat in infilled stream channels, and directly over mineral sands and clays where fibrous peat is absent (Ingram and Otte 1981a). Hemic and sapric peats are principally derived from three plant associations: Atlantic white cedar, gum-cypress, and pocosin (Otte 1981). The former two are most prevalent.

Peat soils in North Carolina have properties that make their management difficult. They are, by definition, high in organic matter (typically 90-95%), and the profile often includes many undecomposed logs and stumps that damage farm machinery as they are exposed by oxidation and subsidence of the soil layer. Since much water is chemically bound to organic matter in the form of colloidial muck, water holding capacity is high (water typically comprises 80-90% of the total weight of soil and water) and hydraulic conductivity low (0.002-0.19 cm/hr, 0.0008-0.07 in/hr), making both drainage and equipment flotation difficult (Lilly 1981a).

To convert pocosin to peat mining, the land must be drained and cleared just as for agriculture (Heath 1975, Campbell 1981, Lilly 1981a). Ditching and drainage are the initial steps with removal of surface vegetation occurring one or two years later. At this time, subsurface wood fragments are removed to a depth of 40 cm (24 in) with a continuous stump-pulling machine (Campbell 1981), or are left to be milled with the peat at a later time. The presence of logs and stumps throughout a deep peat profile may present a costly long-term development problem (Lilly 1981a). The final step prior to harvesting peat involves grading to a 1.5% field slope for surface drainage and elimination of surface wood chips (Campbell 1981, Lilly 1981a). At this point, surface peat may be prepared for harvesting. There are two common methods. The mill method involves scarifying the upper 2.5 cm (1 in) of peat, logs, and stumps into small particles that dry irreversibly. These dry particles are then harvested with a giant vacuum cleaner (Campbell 1981, Taylor 1981). The sod method involves gouging furrows of peat and extruding the pasty peat mass through 80 mm (3.0 in) dies (Campbell 1981). "Sods" typically break off at lengths of 30 cm (12 in) and dry in the field to about 35% moisture content within two weeks (Campbell 1981). The mill method is currently viewed as the most feasible for North Carolina peat operations, though sod techniques have been tested.

Table 16. Area and weight of North Carolina peat deposits (from Otte and Ingram 1980).

Deposit	Area (ha)[a]	Moisture-free Weight (10^9 kg)[b]
I. Pocosin Deposits		
Dismal Swamp	25,000	54
Albemarle-Pamlico Peninsula	93,000	190
Gull Rock	1,600	4
Gum Swamp-Bay City	2,800	4
Light Grounds	2,300	4
Open Grounds	3,900	8
Croatan	10,400	21
Hofmann Forest	2,600	5
Holly Shelter	1,600	4
Angola Bay	5,200	11
Green Swamp	2,600	5
II. Carolina Bays	90,600	181
III. River Floodplains		
Chowan	10,400	22
Roanoke	13,000	26
Tar	2,600	5
Neuse	2,600	5
Cape Fear	5,200	10

[a] 1 hectare = 2.47 acres.

[b] 1 kg = 2.20 pounds.

The economics of peat production in North Carolina are not well understood. Some feel it can be profitable (Harwood and McMullan 1981), but these analyses are theoretical and installation of peat-for-energy technology in eastern North Carolina should be done with extreme caution.

As peat mining on a commercial basis is untested in pocosins, no data exist on environmental effects. However, some impacts can be predicted from either peat mining elsewhere or similar land clearing activities on organic soils developed for agriculture. The most obvious effect is a decrease in elevation due to peat harvesting and natural subsidence (carbon loss by oxidation after irreversible drying of surface peat). In eastern North Carolina, subsidence rates are about 2.7 cm/yr (1 in/yr) for the first two years and 0.4-1.2 cm/yr (0.15-0.46 in/yr) thereafter (Skaggs and Barnes 1976, Tant 1979). These rates are not high compared to other organic soils, but there will inevitably be cumulative effects. In some cases the end result of exhaustive peat harvest and subsidence will be exposure of mineral soil surfaces at or below sea level. These mineral soils may be placed into row-crop agriculture (Taylor 1981); but if the land is to be continually useful, water level management will be necessary (Peat Mining

Task Force 1981). Responsibility for continued water level management upon change of ownership may become a problem, and long-term water management may create or exacerbate saltwater intrusion into freshwater aquifers. Since water tables in mining areas need to be lowered as much as 1.5-2.1 m (5-7 ft) (Peat Mining Task Force 1981) to allow equipment floatation and adequate drying of surface peat, fire hazards will be greater. One fire has already occurred in a mining area on the Albemarle-Pamlico Peninsula (Sturza 1981). Irreversibly-dried peat granules can cause particulate carbon air pollution when swept off peat fields by strong winds. This pollution may severely affect water quality in adjacent rivers, lakes, and streams. Lake Phelps is in close proximity to an area being prepared for an operational peat mine and may be experiencing such pollution (Sturza 1981). If exhausted peat mines become agriculturally productive (Taylor 1981), the silt, organic carbon, herbicides, and pesticides in runoff water will exacerbate current agricultural pollution. (See section on Alteration of Pocosins: Hydrology and Water Quality.) Finally, clearing for peat mining will accelerate the trend of habitat attrition in eastern North Carolina. Many natural plant communities and wildlife populations will be lost. Stuart Critcher (Peat Mining Task Force 1981) indicates that habitat losses from peat mining are similar to those from clearing for agriculture.

Table 17 shows the status of current applications to mine peat in North Carolina. These operations should provide the opportunity for long-term monitoring of peat subsidence, air quality, and water quality, and allow the development of an adequate data base concerning environmental effects.

Table 17. Acreages, location, and status of applications to mine peat in North Carolina as of 6/1/82 (from Peat Mining Task Force 1981 and James Simons, N.C. Department of Natural Resources and Community Development, Raleigh, personal communication).

Applicant	Size (ha)[a]	County Location	State Permit Status[b]
First Colony Farms, Inc.	6151	Hyde, Tyrrell, Washington	Issued 2/21/80
Whitetail Farms	2833	Hyde	Under review
Peatco, Inc.	1457	Pamlico	Under review
Peat Fuels, Inc.	286	Hyde	Issued 11/24/80
Lantern Acres	259	Tyrrell	Under review
American Peat Company	40	Hyde	Issued 9/15/80

[a] 1 hectare = 2.47 acres.

[b] All granted permits expire in 1990.

CHAPTER 7. ALTERATION OF POCOSINS:

IMPLICATIONS OF HABITAT DISSECTION

DISSECTIONS OF NATURAL HABITAT

When natural habitat is urbanized or converted to agriculture or silviculture, it fragments the landscape and the remaining undeveloped land exists as a matrix of habitat islands of various vegetation types and wildlife assemblages. The rate of fragmentation of habitat is dependent on the economic return from modification (Figure 31). Some land, such as arable upland, may be economically valuable immediately upon human occupation, while other land such as wetlands may only be valuable after most other suitable land has been transformed to human use. In any event, once conversion becomes economically advantageous, the fragmentation of natural habitat usually proceeds at a rapid pace (Figures 16 and 17) causing extirpations of local plant and animal species. In south central Wisconsin, 70% of the forested land was modified in a 50-year period (1831-1882) while it took an additional 70 years to modify an additional 15% (Burgess and Sharpe 1981). In Tyrrell County, North Carolina, a county with considerable pocosin habitat, rapid conversion of land to agriculture began about 1970. Between the years 1974 and 1980, this conversion proceeded at a rate of 1.8 % of the total county land area per year (McDonald and Ash 1981). Such conversion rates rapidly fragment the landscape.

A major point of island biogeographic theory is that a large island will contain more species than a smaller one if they are both equidistant from dispersal sources. Moreover, the number of species on larger islands is usually greater than would be predicted by increase in area alone for these reasons: more intra-island habitat diversity, greater opportunity for co-existence of ecological equivalents, and co-existence of different geographical forms (Lovejoy and Oren 1981). If this reasoning is reversed, then the size of habitat islands necessary to support wildlife communities with a large percentage of the regional species may be larger than predicted by theoretical species-area curves. This is particularly true when animals of higher trophic levels are involved (Lovejoy and Oren 1981). These animals use large areas to support their needs and habitat fragmentation often causes "genetic bottlenecks" or reduced gene flow when the few large islands are widely separated. Inter-island distance is especially important when recolonization is necessary (MacArthur and Wilson 1967). Genetic bottlenecks combined with habitat loss swiftly eliminate large herbivores or carnivores from habitat island landscapes.

Field work has borne out the preceeding conclusions, at least in some instances. Matthiae and Stearns (1981) have shown that forest dissection into habitat islands in southeastern Wisconsin has eliminated many large herbivores or carnivores which might be classified as "deciduous forest specialists" (bison, black bear, elk, lynx, moose, wolverine). Further, most of these extirpations took place at relatively large average island sizes or early in the fragmentation process (within the first 35 years). Once islands become depauperate of mammals, they remain so because long inter-island distances limit dispersal (Matthiae and Stearns 1981).

Analysis of bird populations in dissected habitats of several regions of the United States indicates that overall avifauna diversity declines when forest island landscapes are created (Lynch and Whitcomb 1977, Whitcomb et al. 1981). Insectivorous "forest interior" species such as warblers are the most detrimentally affected, while "edge" species such as blackbirds and doves are often unaffected by habitat dissection. These studies also show that nearby undissected forests do not experience similar rates of species loss. An important point made particularly clear by bird studies of forest islands is that, unlike oceanic island studies, terrestrial vertebrates may live in the inter-island environment. These areas are not completely unproductive for wildlife; they simply can not support obligate forest interior species. Edge species such as deer, dove, and quail often do quite well in habitat island landscapes; and since these are game species, the loss of interior species may go unnoticed. Thus, if managers are concerned with obligate island dwellers such as forest interior birds, the concepts of size and location of forest islands must be considered (Whitcomb et al. 1981).

MANAGEMENT UNITS AS HABITAT ISLANDS

When natural habitat is converted to forestry or agriculture, the management units (fields, plantations) may

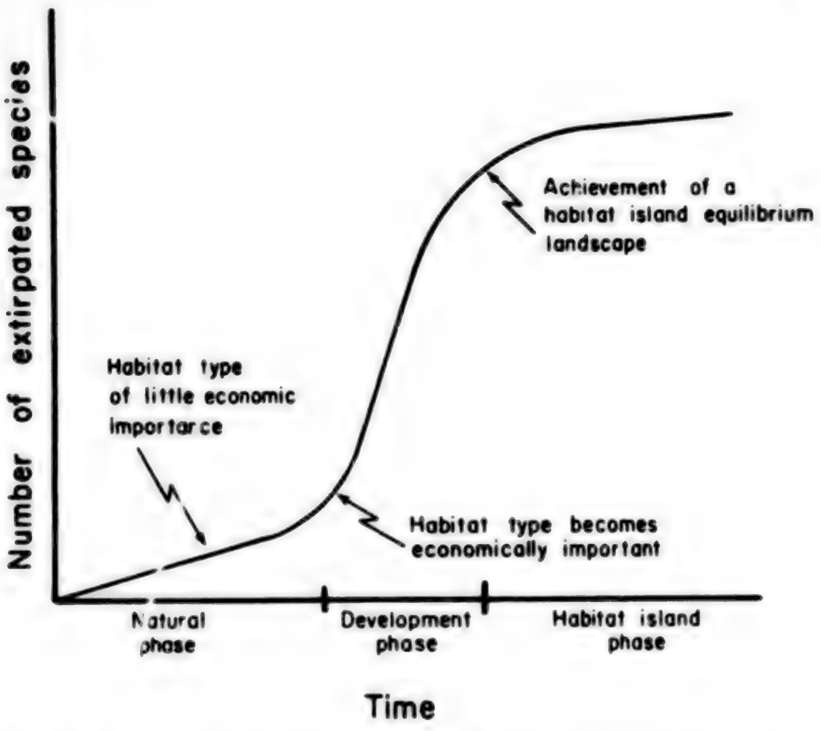

Figure 31. Extirpation of wildlife in relation to conversion of natural habitat.

in some cases be thought of as islands. If fields are left fallow, or if commercial forest stands are in non-harvest stages of rotation, they may be of great use to wildlife. To provide maximum benefit to wildlife, careful attention must be paid to the size, structure, and successional juxtaposition of management units (Meyers and Johnson 1978, Wood and Niles 1978, Harris and Marion 1982, Harris et al. 1982).

The size of islands in managed habitat will correspond to the size of the units being managed. Forest Service or commercial forest blocks are 1000-2000 ha (2470-4940 ac) (Harris and Marion 1982). The average commercial clearcut unit in these blocks is 92 ha (227 ac) in the southeastern United States while the comparable figure for private land is 26 ha (64 ac) (Meyers and Johnson 1978). The size of agricultural fields in eastern North Carolina varies from approximately 8 to greater than 6475 ha (20 to 16,000 ac). With such a wide range in size of management units, it is clear that many units can be managed to benefit smaller wildlife within the boundaries of the unit. However, larger species of wildlife (bear, bobcat, and deer in eastern North Carolina) have ranges exceeding management unit size; thus they must rely on appropriate juxtaposition of smaller units. For this reason, Harris et al. (1982) indicate that the critical size of islands for forest wildlife living on managed lands should not be treated as some set minimum, but as a variable that depends on the size, interspersion, and proximity of other islands.

The quality of management units for wildlife must also be considered. Successional stage and silvicultural type (hardwood or softwood) have much to do with quality of islands for wildlife (Harris and Kangas 1979, Harris et al. 1982). The same would be true to abandoned agricultural land or agricultural fields left fallow or planted for wildlife. In the Southeast, bottomland hardwood stands are of highest quality for wildlife because of their: predominance of hardwoods, occurrence of tree cavities, occurrence of broad-leaved evergreens and abundant mast during winter, high biological productivity, presence of water, and inaccessibility to humans. While none of these characteristics are unique to the bottomlands, the bottomlands are unique because of the simultaneous occurrence of these characteristics (Harris and Mulholland 1982).

Since wildlife islands created by forestry or agricultural management are often smaller than the home ranges of many species of wildlife and since habitat quality of islands will differ greatly, skillful planning should be used to juxtapose islands of different size, quality, and successional stage in a way that benefits wildlife over long periods (Harris and Kangas 1979, Harris and Marion 1982, Harris et al. 1982). This can be accomplished only when wildlife habitat needs are known; when the abilities of the various islands to provide food, cover, and water are known; and when an attempt is made to conform management units to natural patterns of landform, drainage, and soil type (Harris and Kangas 1979). Presently we are unsure of the exact number, sizes, and quality of pocosin islands. Also, there is little published literature on how wildlife use pocosins for food, cover, and water. Seasonal and life-history patterns as well as species-specific utilization of plants by wildlife have not been elucidated. This information is necessary for optimal management of pocosin islands.

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PART 2

MANAGEMENT OPTIONS

CHAPTER 8. CONSIDERATIONS FOR REGIONAL MANAGEMENT

REGIONAL VALUES

Since pocosins are typically interspersed among other natural communities and various types of developed land, it is appropriate not only to consider the management of pocosins but also the management of entire regions where pocosins occur (Figure 32). In the past many values of pocosin regions were taken for granted. These values include: refuges for wildlife, plant communities, and endangered species; high carbon storage with energy resource potential; water storage; recharge to shallow aquifers; contributions of organic matter to estuarine food chains; stabilization of runoff to estuaries; and recreation through hunting, fishing, and sight-seeing. Now, rapid and extensive changes are taking place which could alter these values, often in uncertain and unquantifiable ways. Some of these changes include: possible damage to estuarine structure and resources; permanent loss of elevation through loss of soil and peat; extirpation of some species of wildlife and reduction of wildlife diversity; shifts from slow recharge of shallow aquifers to rapid surface runoff; and a change from naturally slow processes of nutrient cycling and biological activity to more rapid processes whose long-term effects are unknown. Of course, not all portions of the landscape (i.e. different natural communities) possess the same or equal amounts of the values just mentioned. Likewise, not all land-uses alter natural values in the same way or in equal degree. Therefore, the objective of regional management is to match land-uses and natural communities in a way that maximizes both the production of human goods and the preservation of natural values.

MANAGEMENT OF POCOSIN REGIONS

Goals for Regional Management

The following general goals for regional management should help preserve the values of pocosin regions during a period when much of the landscape is being converted to the production of human goods. Other sections of this document provide specific measures for accomplishment of these goals.

1. Preservation of landscape diversity. In areas with little topographic relief, diversity of the landscape can only be achieved by preserving the full range of biotic communities. This also preserves species diversity and improves tolerance of unpredictable stresses, such as disease and fire. Measures which may be taken to maintain landscape diversity include:

a. Maintenance of all natural community types with special consideration given to ones that are restricted or specialized (e.g., savannahs, Atlantic white cedar forests). Swamp forests should be maintained with minimal modification, because it may be impossible to replace their natural functions of sediment filtration, nutrient removal, water storage, storm protection, and wildlife shelter. Likewise, marshes should be maintained without modification because of their indispensable role in the normal functions of estuaries. A few unique areas have been located which should be preserved in their natural state. These are listed in the files of the North Carolina Natural Heritage Program.

b. Maintenance of communities of different sizes. Both large and small areas of all types of communities are needed to accommodate wildlife; corridors are essential to passage and interbreeding. Special consideration should be given to preservation of large tracts, because once subdivided, they are essentially lost.

c. Maintenance of communities of different ages (successional states). Both developing and mature communities are needed to accommodate wildlife and provide a full range of ecological services. Net primary production is usually highest in young communities while stability and nutrient conservation are usually highest in older ones. Preservation of climax communities should be given special consideration because of the many years required for their development.

d. Maintenance of a favorable ratio of developed to undeveloped ecosystems. Intensive development of one area tends to increase the value of natural functions on adjacent undeveloped land. Although optimum balance varies from region to region, computer modeling studies have shown that a 1:1 ratio of developed to undeveloped land may be a

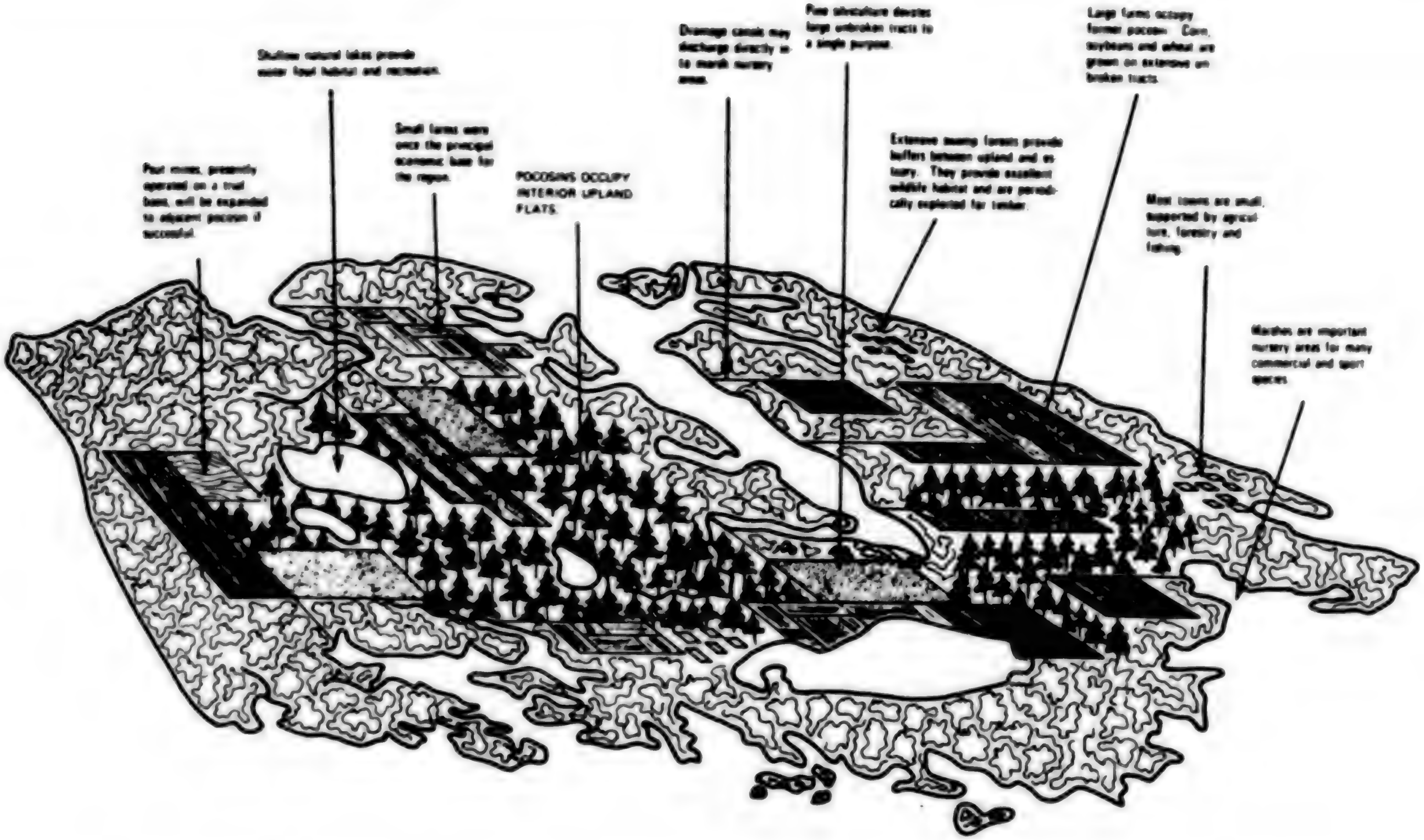
Peat mines, presently operated on a trial basis, will be expanded to adjacent pocosin if successful.
Shallow natural lakes provide water fowl habitat and recreation.
Small farms were once the principal economic base for the region.
POCOSINS OCCUPY INTERIOR UPLAND FLATS.
Drainage canals may discharge directly into marsh nursery areas.
Pine silviculture devotes large unbroken tracts to a single purpose.
Extensive swamp forests provide buffers between upland and estuary. They provide excellent wildlife habitat and are periodically exploited for timber.
Large farms occupy former pocosin. Corn, soybeans and wheat are grown on extensive unbroken tracts.
Most towns are small, supported by agriculture, forestry and fishing.
Marshes are important nursery areas for many commercial and sport species.

Figure 32. The general relationship between natural habitat and land-uses in pocosin regions.

prudent planning goal (Odum and Odum 1972). When this ratio increases to a point much over 2:1, the model predicts a decline in environmental quality.

e. Encouragement of diversity within and between highly developed areas. Since many species of wildlife thrive on intensively developed land and in "edge habitat," potential habitat should be maximized by interspersion of row crops, managed and unmanaged forest land, waterways, and bodies of open water. Treatment of excess drainage water, nutrients, etc. from one sort of highly developed area is also favored by the proximity of other kinds of areas.

2. Maintenance of water quality and control of water level. In pocosin regions, the cumulative effects of large-scale artificial drainage on estuaries are not yet known, although there are definite indications that pulses of fresh water have serious effects on production of juvenile fish. Protection of productive estuarine resources is vital to both commercial and sport fisheries. For this reason management measures should include:

a. Control of runoff and its nutrient and chemical components at the source.

b. Use of natural and artificial features of the landscape to maintain and control both quality and quantity of runoff.

c. Establishment of quality standards for runoff reaching estuaries and freshwater lakes and an expanded, continuous monitoring program for enforcement of standards and informed planning.

d. Establishment of policies on water level control to promote denitrification and prevent loss of soil by oxidation and fire.

Steps for Effective Management

In order to preserve the natural values of a region and simultaneously maximize its production of human goods and services, it is necessary to accomplish the following tasks (Wuenscher and Starrett 1973):

1. Identify the characteristics and significance of the various features of the natural landscape and the various land-uses of the region.
2. Develop criteria by which the natural features and land-uses can be identified.
3. Analyze regional land characteristics and locate the natural features and land-uses on the ground.
4. Establish overall management goals for the region being considered. (See previous section for general goals.)
5. Develop procedures (regulations, public involvement, public awareness and understanding) that facilitate accomplishment of the established goals.

Identification of the characteristics and significance of components of the various features of the natural landscape and various land-uses of the region (Tables 18-19) is the first step in regional management. For the most part, the contents of Tables 18-19 have already been elaborated through the investigations of numerous researchers. Our understanding, however, is far from complete and in some cases woefully inadequate. Far more work needs to be done in many areas, particularly those of soil-nutrient-water interactions and wildlife ecology. Until work can be done, though, planning will have to be based on present levels of understanding.

Although boundaries between natural communities and/or land-uses are often indistinct, they can be delineated by use of certain criteria. The North Carolina Land Policy Council (1974) developed criteria for identification of "Areas of Environmental Concern" which are basically equivalent to natural communities and land-uses. Their document, Criteria for the Identification of Areas of Environmental Concern provides definitions, discussions of significance, and techniques for identification of 29 types of physiographic areas, four types of developmental sites, and 10 types of land in public trust (Table 20). Areas are identified by such criteria as vegetation, land form, soil type, geologic features, established evaluation indices (for instance, Soil Conservation Service land capability classes are used to identify prime agricultural land), political boundaries, hydrologic data, and historical records.

Identification and determination of the exact location of natural communities and land-uses is facilitated by maps available from numerous sources. North Carolina has established the Land Resources Information Service to centralize and computerize many types of information in map form. In addition, an Environmental Geologic Atlas is being prepared for the Albemarle-Pamlico peninsula. Four overlays developed for use with standard U.S. Geological Survey topographic maps (1:24,000) show land use/land cover, physical properties, active processes, and water drainage and bathymetry, while two other maps at scales of 1:250,000 show mineral and energy resources and demographic data (Craig Lukin, East Carolina University, Institute of Coastal and Marine Resources, personal communication). The preparation of similar maps for other regions of the state would be invaluable.

ACHIEVING GOALS FOR REGIONAL MANAGEMENT

Accomplishment of goals for regional management requires some government involvement. Various federal and state acts such as the Federal Water Pollution Control Act Amendments of 1972, the Coastal Area Management Act, and the Endangered Species Act of 1973, have been passed to protect fish and wildlife and preserve the quality of land, air, and water. In addition to these regulatory acts, various nonregulatory inducements, such as tax reductions, are available to encourage land stewardship. A firmly established, tax-reducing incentive is the gift to a non-profit organization. A number of national, state and even local private organizations have been formed to receive gifts of land and then manage them for conservation purposes (Appendix

Table 18. Characteristics and significance of the predominant land-uses in pocosin regions.

Land-Use	Characteristics	Significance
Agriculture	1. Highly productive	1. Can contribute significantly to the regional economy.
	2. Most efficient in large blocks.	2. Uses large tracts that might otherwise be in natural vegetation.
	3. Only practical for certain soil types.	3-4. Necessitates careful planning prior to development.
	4. Requires elaborate site preparation.	
	5. Requires extensive drainage modifications.	5. Alters hydrologic regimes and increases possibility of detrimental freshwater discharges into primary nursery areas.
	6. Leaves soil unvegetated for extended periods.	6. Increases potential for soil erosion.
	7. Requires special soil amendments.	7. Increases potential for non-point source pollution.
	8. Requires large fuel inputs.	8. Necessitates high productivity to offset high operating costs.
Intensive Forestry	1. Highly productive.	1. Contributes to the regional economy but supports a much smaller work force than agriculture.
	2. Only practical for certain soil types.	2-3. Necessitates careful planning prior to development.
	3. Requires site preparation.	
	4. Requires some drainage modification.	4. Alters hydrologic regimes particularly during early growth stages when efficient drainage is needed for good stand establishment.
	5. May require some soil amendments.	5. Increases potential for pollution, particularly during early years of stand establishment.

(continued)

Table 18. (concluded)

Land-Use	Characteristics	Significance
Intensive Forestry (continued)	6. Develops as a closed canopy monoculture during most of rotation period.	6. Eliminates ground cover and reduces wildlife productivity.
	7. Requires fire control and management.	7. May affect communities and/or species that are adapted to fire.
Peat Mines	1. Will exploit a little-used energy source.	1. Will contribute to the regional economy.
	2. Will destroy existing natural vegetation.	2. Removes wildlife habitat.
	3. Will reshape landscape.	3. May affect surface drainage, subsurface drainage, groundwater storage, and groundwater discharge in unforeseen and detrimental ways.
	4. Require special drainage and water management.	4. Alter hydrologic regimes and increase possibility of detrimental discharges into primary nursery areas.
	5. May produce land suitable for agriculture once peat mining is complete.	5. Benefits and problems associated with agriculture would then be increased.
Towns	1. Provide special services and facilities.	1. Require careful planning to insure that public services can be furnished without environmental degradation.
	2. Tend to consume land at the rural-urban fringe.	2. Require careful planning to insure orderly growth.
Wildlife Management Areas	1. Often located on land with limited potential for other development.	1a. Relatively extensive in pocosin regions but still a minor land use. 1b. Will increase in importance as adjacent lands are developed.
	2. Economic input and habitat manipulation often minimal.	2. Produce little change in natural communities.
	3. Management usually emphasizes game species.	3. Management for game species is needed for public support, but could be detrimental to some species.

Table 19. Characteristics and significance of the natural communities of pocosin regions.

Community-Type	Characteristics	Significance
Natural Pocosins	1. Often present in large contiguous blocks.	1-2. Provide shelter for reclusive species.
	2. Generally inaccessible.	
	3. Maintain own high water table.	3. Act as groundwater storage areas and reduce runoff rates.
	4. Often have low primary productivity.	4. Support relatively little wildlife per unit area.
	5. Organic soils.	5. Provide carbon storage and a potential peat energy source.
	6. High fire susceptibility.	6. Produce a diversity of successional stages.
Savannahs	1. Geographically limited.	1. Vulnerable to destruction.
	2. Support a diverse group of organisms.	2. Have high aesthetic, recreational, and scientific value.
	3. The principal habitat for a number of endangered plants and animals.	3. Important for preservation of genetic diversity.
	4. Require frequent fire to maintain integrity.	4. Need special management.
Gum-Cypress Swamp Forests	1. High productivity.	1. Support abundant wildlife.
	2. Dominated by hardwood species.	2. The best source of food and shelter for many species.
	3. Geographically extensive.	3a. Provide natural travel corridors for wildlife.
		3b. Slow runoff and reduce storm surges.
	4. Often inaccessible.	4. Human intrusion is reduced benefiting reclusive species.
	5. Maximum soil-water interaction.	5. Help remove excess nutrients and other pollutants.

(continued)

Table 19. (continued)

Community-Type	Characteristics	Significance
Gum-Cypress Swamp Forests (continued)	6. Organic soils.	6. Store carbon for gradual release to river and estuaries.
	7. High water table.	7a. Groundwater storage. 7b. Types of usage are limited.
Atlantic White Cedar Swamp Forests	1. Relatively limited in geographic extent.	1-2. Vulnerable to depletion.
	2. Valuable timber resources.	
	3. Have specific requirements for establishment and regeneration.	3. Need special management.
Streams	1. Receive water drained from organic soils.	1. Water normally of good quality although stained and acid.
	2. Generally undeveloped.	2. Good recreational and scenic value.
	3. Peak flow usually in early spring.	3. Important as a spawning and nursery area for several species of anadromous fish.
Lakes	1. Usually quite shallow	1-3. Often valuable for waterfowl, freshwater fish, and recreation, but value and usage depend on the specific characteristics of each lake.
	2. Vary in size.	
	3. Water chemistry varies from lake to lake.	
	4. Most maintain water level by a balance between precipitation and evaporation.	4. Levels and quality of water could be altered by local drainage modifications.
Marshes	1. Extremely high productivity.	1. Support abundant aquatic and wetland wildlife.
	2. Occupy shallow water adjacent to deeper bodies.	2. Provide protection for juveniles of many species.
	3. Organic soils.	3. The only suitable substrate for the juveniles of many species.

(continued)

Table 19. (concluded)

Community-type	Characteristics	Significance
Marshes (continued)	4. Often geographically extensive.	4. Provide shoreline protection and reduce storm damage.
Open Water of Estuaries	1. Geographically extensive.	1. A resource of diverse usage.
	2. Variable and fluctuating salinity.	2a. Highly productive for a limited number of species.
		2b. A regime to which relatively few species have managed to adapt.

F). These groups are often quite flexible in their manner of receiving land with the gifts usually falling into the categories of outright conveyances, bargain sales, easements, and various estate arrangements (Sussman and Roe, undated).

The greatest tax advantage usually derives from outright conveyance or estate gifts, but sometimes this is impractical. One alternative is the bargain sale where the land is sold at a substantially reduced price with the seller then claiming the difference between sale price and full market value as the charitable donation. Another alternative is the gift of an easement in which the owner retains the land but forfeits certain development rights. If established in perpetuity, the easement becomes a permanent part of the land that transfers from owner to owner. Since easements usually reduce market value of land, this reduction determines the amount of the charitable donation. As well as gifts, sales to charitable organizations are sometimes possible but this, of course, eliminates the tax advantage.

Programs that pay landowners for their conservation practices are an alternative to tax reduction. Some programs used in the past that should be continued or might be revived and redesigned specifically for conservation of fish and wildlife and other public resources are (Leitch and Danielson 1979):

1. Migratory Bird Hunting Stamp (Duck Stamp) Act of 1934 as amended by PL 85-585 in 1958. This program is administered by the U.S. Fish and Wildlife Service and allows Federal purchase of land or purchase of easement rights to prevent draining, filling, burning, or leveling of wetlands.

2. Agricultural Conservation Program authorized by the Agricultural Adjustment Act of 1933. This was a cost sharing program between landowners and the Federal government that, among other things, promoted land drainge. Cost sharing for open ditch drainage, tile drainage, and land leveling to facilitate drainage ended in 1978. Until 1973, the program also cost shared for creating shallow water areas for wildlife, and it might also be designed to incorporate wildlife considerations into drainage projects.

3. Conservation Reserve Program authorized by the Soil Bank Act of 1956. The purpose of Soil Bank was to divert land from production of crops, livestock, and their products; to conserve soil during the diversion period; and to stimulate tree planting, water impoundments, and wildlife conservation. This program provided payments to participating landowners for three to ten-year contract periods. The final year for enrollment in Soil Bank was 1960.

4. Cropland Adjustment Program authorized by the Food and Agriculture Act of 1956 (PL 89-321). Similar to the Soil Bank, this program was designed to shift cropland to conservation use. It offered payments to landowners if they would allow public use without charge for hunting, trapping, fishing, and hiking, and it provided grants to government agencies to help them acquire eligible cropland and convert

Table 20. Areas with established criteria for identification (from North Carolina Land Policy Council, 1974).

Physiographic Areas	Developmental Sites	Land in Public Trust
Tidal marshlands	Large-scale developments	State nature and historic preserve
Freshwater wetlands	Key facilities	State parks
Riverine floodways	Reservoir shorelines	Primitive and wilderness areas
Estuarine flood areas	Projects of regional significance	Historic sites
Open coast flood areas		Public rights-of-way
Areas of rural scenic quality		State forests
Park zones		Beaches
Blue Ridge Parkway zone		Low tidal marshlands
Beach erosive areas		Estuarine lands
Coastal inlet lands		Lands under the marginal sea
Dunelands		
Frontal dunes		
Seismic zones		
Unique natural areas		
Prime agricultural land		
Critical erosion areas		
Critical mineral sites		
Slope constraint areas		
Prime forestry land		
Trout habitat		
Wildlife management areas		
Water quality limited areas		
Areas with groundwater problems		
Public water supply watersheds		
Areas with limitations for septic tanks		
Well fields of public water supplies		
Areas of high air pollution potential		
Noise hazard areas		
Rare animal habitats		

it permanently to open space, wildlife, or recreation facilities, or for the prevention of air or water pollution. Money for contracts was appropriated only during the first two years of this program with only 3.2 million ha (8 million ac) enrolled nationwide.

5. Cropland Conversion Program authorized by Title I of the Food and Agriculture Act of 1962 (PL 87-703). It provided three to ten-year agreements with landowners to convert cropland to grass, forests, outdoor recreation, or wildlife development. Participating farmers received adjustment payments, cost-share payments, and technical assistance.

6. Federal Water Bank Program authorized by PL 92-559 in 1970 and administered through the Agricultural Conservation and Stabilization Service. Fifteen states are authorized to participate (North Carolina is not included) and each is allocated $10 million per year. The program is designed to improve wetlands and habitat for wildlife along with other soil and water conservation objectives. It provides annual payments to landowners to maintain upland areas adjacent to wetland during ten-year contract periods with payments based primarily on the value of potential agricultural production from contract lands.

These programs provide a sample of incentive possibilities, and although often expensive, they have some advantages over other measures. In a nation with a history of private land ownership and its sovereign rights, it is sometimes difficult to enforce even the most basic health and safety standards. Incentive programs avoid the problem of enforcement by offering inducements rather than penalties. Incentive programs also fill the gap between inaction and purchase of large refuge areas. It is usually impractical for public agencies or private groups to purchase and manage numerous small isolated holdings even in those cases when it is obvious that a group of small holdings can have more value for wildlife than a single refuge of comparable size. Incentive programs keep land in private ownership and make individual citizens the "refuge" managers.

CHAPTER 9. WATER MANAGEMENT ON CONVERTED POCOSINS

WATER PROBLEMS ASSOCIATED WITH LAND CONVERSION TO AGRICULTURE

It has been shown that conversion of pocosins and related areas to cropland substantially increases runoff discharge rates, nutrients, and sediments (Kirby-Smith and Barber 1979, Skaggs et al. 1980, Daniel 1981). Researchers have found that pulses of freshwater discharged into primary nursery areas can result in reduced and unstable salinity which is related to lowered production of economically important estuarine species (Jones and Sholar 1981). Investigators who have studied estuarine nutrient cycling recommend that inputs of inorganic nitrogen to the Pamlico River Estuary be restricted in order to minimize algal blooms which already occur (Kuenzler et al. 1979). They caution that an increase in nutrient inputs to Albemarle Sound could become detrimental if changes in existing conditions were to occur, such as extension of the present range of blue-green algae into new areas of the Sound (Bowden and Hobbie 1977). The North Carolina Division of Environmental Management has recommended that inputs of both nitrogen and phosphorus to the Chowan River and Albemarle Sound be reduced.

However, farming operations on former pocosins have existed for many years, and additional land is continually being brought into production. The question of how much land can be converted without detrimental impacts on other ecosystems should be answered in part by considering what actions can be taken by landowners to mitigate impacts, especially those on surrounding estuaries.

AGRONOMIC PRACTICES FOR REDUCTION OF POLLUTANTS

On-site agronomic practices can reduce problems associated with nutrients and pesticides in runoff. The following recommendations which may specifically benefit the low, wet, flat, highly organic soils of the eastern Coastal Plain have been selected from a survey of practices for reduction of both soil erosion and nutrients and pesticides found in Stewart et al. (1975), Control of Water Pollution from Cropland: Volume I, A Manual for Guideline Development, published jointly by the U.S. Environmental Protection Agency and the U.S. Department of Agriculture.

Practices to Control Nutrient Losses from Fields

Fertilization with phosphorus on organic soils should be restricted to levels that are immediately utilized by crops. Studies by Skaggs et al. (1980) on corporate farmland show that large excesses of phosphorus leave the land in surface runoff because of the low capacity for phosphorus adsorption by organic soils. Reduction of excesses might be accomplished by more frequent fertilizer applications in smaller amounts, accompanied by annual soil testing to determine actual needs. Requirements for nitrogen fertilizer must be established by determination of the nitrogen-supplying capacity of local soils. Fertilizer applications can be timed to coincide with the optimum period of plant uptake; for example, nitrate should be applied to corn about three to four weeks after emergence. Split applications may help to prevent large excesses. Fall application of ammonium fertilizer is a poor practice in eastern North Carolina because more than half of the ammonium may be converted to soluble nitrate which can then be lost by leaching (Stewart et al. 1975). In contrast, loss of nitrogen is insignificant when ammonium is applied in spring two weeks before corn planting. Rotation of plants with different nitrogen requirements (for example, soybeans with corn) can reduce the amounts of leachable nitrogen in the soil and has additional advantages for control of pests and soil erosion.

Natural processes of nitrogen treatment can be enhanced by retaining water on the land during periods when efficient drainage is unnecessary. Flashboard risers (Figure 26) and gates in drainage canals can significantly lower nitrate levels during winter when crops are not grown (Gilliam et al. 1978). High soil water levels favor denitrification of nitrate and escape of nitrogen gases into the atmosphere. Although maintenance of a high water table in winter may have "uncertain" effects on soil structure (Gilliam et al. 1978), this possibility must be weighed against soil changes through slow oxidation, subsidence, and fire which will occur with constant artificial drainage.

Pesticide Management

The most serious and recurrent problems in pesticide use originate from aerial pesticide applications. This problem requires special attention in pocosin regions because of proximity to estuarine fisheries. High levels of contamination occur through aerial drift of pesticides or by direct, inadvertent application of aerial spray to surface waters. Although care in spraying or use of helicopters can reduce the problem, it cannot be entirely eliminated. Aerial spraying should therefore be used only in critical situations, such as sudden pest outbreaks. Regular insect and weed surveys by qualified persons can minimize the quantity of pesticides needed. Rather than spraying entire fields, selective treatment of infested areas may produce adequate control.

Whenever possible, pesticides should be incorporated in narrow bands below the surface of the soil in order to reduce the amount of pesticide needed. Precision subsurface application is more expensive but can cut pesticide requirements in half. Because of the tendency of many pesticides to bind to soil organic matter, surface application may be necessary on some organic soils (Lilly 1981a).

Integrated pest management, using a combination of chemical, biological, cultural, and mechanical methods, can result in a substantial reduction in pesticide use and costs. Farming interests and agricultural agencies can cooperate to establish demonstration projects in integrated pest management. Further research and pilot-scale experimental applications can be carried out with biological pest control methods, which have shown good results in some cases but have not been extensively applied to crops.

Optimum rates of pesticide applications in specific geographic regions may deviate from officially recommended rates issued on a national basis. Experimentation to determine the effectiveness of reduced rates of application in pocosin regions could be carried out cooperatively by private farmers and government agencies.

Alternation of pesticides in successive growing seasons will reduce the development of pest resistance and minimize accumulations of individual pesticides in soil or receiving waters. A list of alternative interchangeable pesticides can be consulted for this purpose.[5] However, since many pesticides are inactivated by binding to organic matter, there are fewer pesticides suitable for use on organic soils and sometimes no alternative exists (Lilly 1981a). Crop rotation can result in interruption of pest life cycles and consequent reduction of the amount of pesticide needed. This method is widely practiced in the Tidewater area.

When possible, pesticide application should be carried out to avoid times of high rainfall and runoff. Postemergence pesticide applications and application after the crop canopy is closed are preferable to preemergence applications.

Tillage or mechanical cultivation can be effective in weed control and may be used where conditions warrant. However, increased mechanical manipulation may result in increased erosion and damage to soil structure through compaction by heavy equipment. Since a reduction in tillage often requires increased use of herbicides, there must be careful consideration of site and soil type before a control plan is selected.

Erosion and Sediment Control

Soil losses by erosion can be reduced by increasing rainfall infiltration and reducing runoff velocity. Rainfall infiltration into the soil can be promoted in several ways. One method is maintenance of dense vegetative cover. Adequate, but not excessive, fertilization favors development of a dense crop stand, which increases infiltration and potential for evapotranspiration. Keeping land in continuous meadow results in the lowest surface runoff of any agricultural practice other than forest (Stewart et al. 1975). Maintaining cover and green manure crops can minimize soil exposure and reduce raindrop impact (U.S. Soil Cons. Serv. 1978). These practices may be combined with no-till methods, which can reduce spring runoff surges when crop residues are allowed to remain on the land. Increases in soil temperature and drying are moderated. Labor, machinery, and fuel expenses are decreased, and compaction of the soil is reduced, which favors infiltration. Increased amounts of pesticides may be required (Stewart et al. 1975). No-till methods are being increasingly utilized in the Washington-Tyrrell-Hyde County region (R. Croom, personal communication).

Slowing runoff velocity can be done with field border strips or vegetated filter areas. Although not effective in reducing soil losses from agricultural fields, these can serve to trap some sediments near the source (Stewart et al.

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[5] N.C. Agricultural Chemicals Manual. Updated yearly. Available from Division of Continuing Education, P.O. Box 5125, Raleigh, NC 27650. Attention: Mr. Bruce Winston. $5.50 per single copy.

1975). This is a practice recommended by local Soil Conservation Service offices (R. Croom, personal communication). Pond storage of runoff water can decrease runoff, trap sediment, and reduce nutrient and pesticide concentrations through chemical transformations and sedimentation. Water stored in the pond is available for irrigation during times of drought. Construction of ponds may have other beneficial effects such as enhancement of wildlife habitat. Since nutrients and pesticides tend to be adsorbed to fine sediment particles such as silt, clay, and particulate organic matter, which remain in suspension at low velocities, slowing the velocity of runoff may have limited effectiveness in reducing nutrient and chemical loads reaching receiving waters. Agronomic practices to reduce soil erosion must therefore be used in combination with other management measures that control the amounts of chemicals at the point of application.

Since sediment yield to receiving waters is a function of both gross sediment erosion and area of the watershed (Stewart et al. 1975), soil loss estimates alone may not give a realistic concept of sediment yield to estuaries. Although soil losses from fields in the flat eastern Coastal Plain may be much less than those in the Piedmont (approximately 5 ton/ac/yr (13 x 10^3 kg/ha/yr) vs. 15-20 ton/ac/yr (39-52 x 10^3 kg/ha/yr); R. Croom, Soil Conservation Service, personal communication), sediment yield to estuaries from the Piedmont may be proportionally less because of the greater distance from the source and the sediment-trapping effect of reservoirs and river floodplains. Piedmont fields tend to be small and interspersed with "buffer areas" of woodland and streamside vegetation which can trap sediment. This situation does not exist in areas of Hyde, Tyrrell, and Dare counties where field sizes are commonly 10-50 km^2 (4-19 mi^2) and uninterrupted by natural vegetation. Agricultural lands in pocosin areas are much closer to estuaries, and runoff is routinely discharged through canals directly to estuaries.

For the purpose of monitoring and reducing water pollution from soil erosion, sediment yield tolerance limits to adjacent water bodies can be established for local areas, taking into account texture of soil, distance from receiving waters, and allowable peak loads from storms (Stewart et al. 1975). Research into the fine particle and colloidal sediment load of runoff water in the eastern Coastal Plain may be required to establish such limits.

Decision-Making and Implementation of Best Agronomic Management Practices

Decisions for best on-site management practices should utilize all pertinent information on soil type, elevation and slope, erosion potential, appropriate crops, and appropriate fertilizers and pesticides. A systematic flow-chart method for decision making is demonstrated in the manual Control of Water Pollution from Cropland, Volume I, Section 6, pp. 97-111. A flow chart involving nutrient problems and control practices (Figure 33) provides an example of this method which can be employed cooperatively by private interests and government agencies to develop optimum practices tailored to pocosin regions. This system will indicate which of the numerous control practices can be utilized effectively and will help decision-making when a compromise must be made between imperfect alternatives.

The supervision, advice, and assistance of large corporate farming operations should be made available to individual farm operators who lease land from corporations. This will provide accountability as well as increasing the likelihood that methods of fertilizer and pesticide application and other agronomic practices are utilized which have least impact on public resources.

WATER MANAGEMENT ON COMMERCIAL FOREST LANDS

Effects of silviculture on quality of runoff water have been described as "short-lived impacts that move from place to place as management activities proceed through the forest" (Dissmeyer and Singer 1977). Good forestry management involves increasing vegetation cover and minimal disturbance of soil, which generally acts to maintain rather than degrade water quality. Although long-term average water quality from silvicultural lands is generally considered good, this does not rule out the need for attention to periodic localized disturbances which are sources of potential pollution. Major areas of concern appear to be roads, forest tracts adjacent to waterways, and pesticide use.

Pollution from forest lands is best controlled by proper forest management rather than after-the-fact treatment of drainage water. This approach is implemented through three strategies: (1) care in introducing potential environmental pollutants into forests, (2) management of forest environments for minimum generation of pollution, and (3) containment of pollutants within forest boundaries (U.S. E.P.A. 1973).

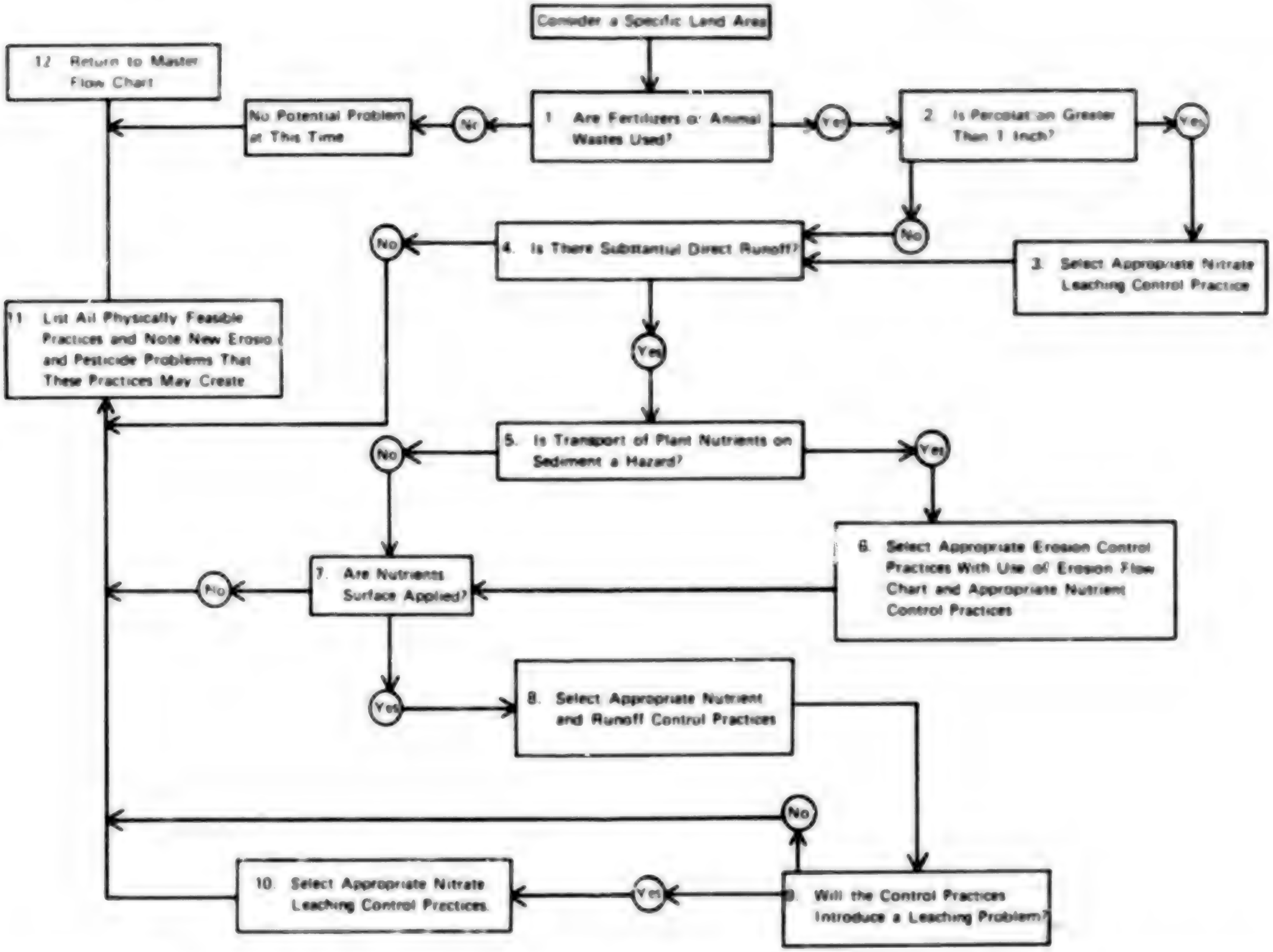
Consider a Specific Land Area
1. Are Fertilizers or Animal Wastes Used?
No
No Potential Problem at This Time
12. Return to Master Flow Chart
Yes
2. Is Percolation Greater Than 1 Inch?
Yes
No
3. Select Appropriate Nitrate Leaching Control Practice
4. Is There Substantial Direct Runoff?
No
Yes
11. List All Physically Feasible Practices and Note New Erosion and Pesticide Problems That These Practices May Create
5. Is Transport of Plant Nutrients on Sediment a Hazard?
No
Yes
6. Select Appropriate Erosion Control Practices With Use of Erosion Flow Chart and Appropriate Nutrient Control Practices
7. Are Nutrients Surface Applied?
No
Yes
8. Select Appropriate Nutrient and Runoff Control Practices
No
9. Will the Control Practices Introduce a Leaching Problem?
Yes
10. Select Appropriate Nitrate Leaching Control Practices

Figure 33. Example of a decision-making flowchart for assessing potential nutrient problems and selecting feasible control practices (from Stewart et al. 1975).

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Areas Adjacent to Ditches, Streams, and Water Bodies

Because of the potential for water pollution by periodic forestry operations, intensive management for maximum wood production should not be practiced near ditches, streams, or other bodies of water. An effective practice is employment of buffer strips between areas of erosion and watercourses. The need for strategically-placed buffer strips is emphasized repeatedly in references dealing with water quality of drainage. Within buffer strips, only selective harvesting should be practiced, and use of heavy equipment, prescribed burning, and application of fertilizers and pesticides should be avoided (Dissmeyer and Singer 1977, Corbett et al. 1978, N.C. Div. of Envir. Management 1979, and others).

Desirable widths of buffer strips will vary with soil type, slope, and types of pollutants. Data on exact widths for coastal plain soils and hydrologic conditions are lacking. The following recommendations for other areas are summarized primarily from the handbook, Processes, Procedures and Methods to Control Pollution Resulting from Silvicultural Activities (U.S. E.P.A. 1973).

For thermal pollution, widths of buffer strips can be determined by inspection of the height of vegetation required to shade the stream or channel. For pesticides, a set of estimates based on method of pesticide application has been proposed by Schlapfer (1973). For aerial, ground vehicle, hand spraying, and hand injection methods respectively, untreated strips of 30, 15, 7.5, and 4.5 meters (100, 50, 25, and 15 ft) are recommended adjacent to watercourses.

For sediment erosion, it is important to note that the principal concern is the actual amount of suspended sediment in runoff, rather than an estimate of erosion from the site (U.S. E.P.A. 1973). Based on a site in the White Mountains with well-drained sandy loam soil and a hardwood leaf litter of 5-10 cm (2.5-4 inches), Trimble and Sartz (1957) recommend protective strips of 7.6 m (25 ft) on level land with an additional 0.6 m (2 ft) for each 1 percent increase in slope. The U.S. Forest Service (1973b) recommends strips ranging from 9 m (30 ft) for level land with slight erosion hazard to 40 m (130 ft) for land with 20 percent slope and severe hazard. Morris et al. (1979) recommend 20 m (65 ft) strips adjacent to stream channels in floodplain forest sites.

Use of the Universal Soil Loss Equation for determining proper widths is suggested by the E.P.A. (1973), but this has limited applicability in pocosins because soil erodibility values for typical highly-organic North Carolina soils are not available (U.S. Soil Cons. Serv. 1981). However, the lack of specific data should not prevent establishment of buffer strips within the ranges recommended above.

Roads

Roads constructed for access and harvest are the areas of greatest soil loss on silvicultural lands (U.S. E.P.A. 1973, Patric 1976). Since sediment erosion from roads is potentially more important than from areas undergoing clearcutting, road construction should be held to a minimum and carefully planned (U.S. E.P.A. 1973). When soil is saturated, use by heavy equipment should be limited (U.S. E.P.A. 1973). After harvest, roads should be closed, seeded with vegetation, and barricaded unless they are suitably maintained for permanent use (N.C. Div. of Envir. Management 1979).

The U.S. E.P.A. (1973) recommends that forest buffer strips of 30 m (100 ft) be left between roads and streams. Since roads in pocosins are commonly built from canal spoil, this recommendation would be difficult to adopt. On some roads, however, a gutter ditch for sediment interception is placed between the road and canal with a buffer strip of several meters of weeds and shrubs between the ditch and canal. Monitoring of the effectiveness of this practice and other possible methods of trapping sediment from roads should be carried out for pocosin regions.

Pesticides

Since the effects of pesticides on forests are as yet very uncertain (U.S. E.P.A. 1973), extreme caution should be exercised in their use. Application should be as specific and precise as possible, using such measures as injection of individual diseased trees; selective treatment of small areas where a problem has been identified; and avoidance of aerial application. Pesticides should not be applied in buffer zones.

Experimental applications of herbicides and insecticides in some very young plantations have improved growth and these practices may be expanded (J. Hughes, personal communication). In these areas, herbicides and insecticides are applied at the base of individual seedlings or in narrow bands.

Small Landholding Management

In small private holdings, managed regeneration of harvested plots is often neglected because of the substantial investment required (C. Franklin, personal communication). Timber sale contracts may be very informal, often only verbal, and usually require few performance standards. Funds provided through the Landowner Assistance Program are completely utilized each year. This program serves only a fraction of the landowners desiring assistance, and landowners may wait until they can obtain funds through the program before installing best management practices (BMPs) (C. Franklin, personal communication).

The North Carolina Division of Environmental Management (1979) recommends several practices for improvement of forestry management on small private landholdings. An educational effort could inform small landowners of proper management measures for protection of water quality, advise them of their right to require posting of performance bonds by private timber harvest contractors, and provide them with sample contracts which include specific requirements for recommended management practices with grounds for legal enforcement. Property tax incentives or credits could be implemented to reward landowners for the increased time and expense in carrying out BMPs. These measures would require increased funds for additional agency staff time as well as direct financial assistance (N.C. Div. of Envir. Management 1979).

WATERSHED MANAGEMENT

Although sediment, nutrient, and pesticide control should be exercised at the source by suitable agronomic practices, further management and treatment of water can be implemented by planning at the watershed level. Detailed investigations of agricultural inputs in the Kissimmee-Lake Okeechobee watershed in Florida supply information which may be applicable to pocosin areas (Florida Dep. of Admin. 1976). Since high flows are effective in resuspending phosphorus from sediment pore waters and flushing accumulated sediments and associated nutrients and pesticides downchannel, the Florida study recommends that landowners implement on-the-land detention to accommodate stormwater from a once in a year, 10-year design storm of 24 hours duration (assuming that 20 cm (8 in) of rain falls in 24 hours). The study recommends that restrictive devices such as weirs or flashboard risers be installed to prevent discharge from detention areas (marshes or impoundments) from exceeding peak discharge rates under natural conditions (Hurst 1976). For planning watershed management and cost sharing of large projects, the formation of cooperatives of individual landowners in a watershed is suggested (Fla. Dep. of Admin. 1976).

Management measures from a variety of other sources are summarized in the following section. Although they are based on valid principles, generally their practical effectiveness has only been demonstrated in small-scale pilot projects. Pocosin regions offer an exceptional opportunity for further trials of some of these methods through cooperation between academic, government, and private interests.

Diversion of Freshwater Runoff from Saline Nursery Areas to Open Shoreline

Jones and Sholar (1981) proposed that agricultural discharge be diverted away from saline primary nursery areas to more open areas of estuarine shoreline (Figure 34). This diversion may eliminate large pulses of fresh water in nursery areas and help maintain normal salinity patterns necessary for optimum production of shrimp and other aquatic species. Other potential problems such as sedimentation and nutrient loading of nursery areas would also be prevented. Water control devices could be installed in existing canals and flow diverted to new canals when necessary, for example, during the critical nursery months of April, May and June. Before such diversion canals are constructed, however, an evaluation of other environmental effects should be made.

Sheet Flow of Runoff through Wooded Swamps from Canal Discharge Points and Pump Stations

Runoff water can be spread over the floor of swamp forests where it may be detained before emptying into creeks or waterways. This detention can reduce velocity, allowing sedimentation to take place, and increase residence time allowing for biochemical treatment of nutrients and pesticides and nutrient uptake by vegetation. With sufficient detention time, this method is effective for reducing concentrations of nitrate. Effects on phosphorus and pesticides are not as clear.

Increased production of some species of vegetation and changes in community composition and diversity can occur with increased nutrient loading in wetlands (see section on Experimental Wastewater Application to Wetlands) Species vary

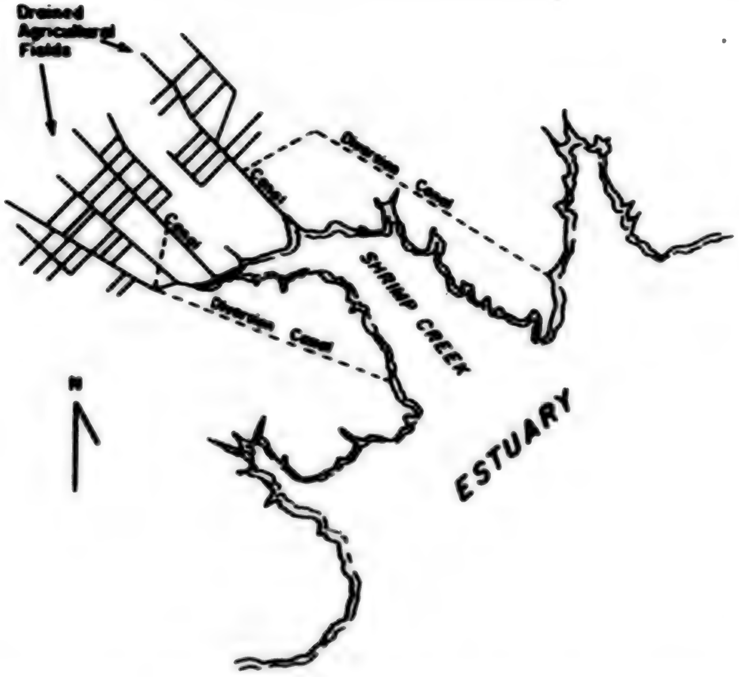

Figure 34. Diagram of hypothetical plan for rerouting of canals to divert agricultural discharge from an estuarine nursery area to open shoreline.

in their ability to withstand increased flooding; this information is well summarized for trees and shrubs in Teskey and Hinckley (1977). Species composition and expected changes in water level and duration of flooding need to be determined in order to predict tolerance and survival. Diversion of discharge through unique or valuable swamp communities should be restricted until vegetative responses are known. For example, the cumulative effects of improper discharge into small but numerous Atlantic white cedar stands could be detrimental. Provisions should be made for careful monitoring of species responses in any swamp community used for discharge.

Several studies show that slow velocity and a certain detention time, possibly up to several days, are necessary for effective nutrient treatment by wetlands. A narrow fringe of wetland forest may not provide sufficient detention time to cause significant nutrient removal from a large volume of water, although slowing of velocity may allow some sedimentation. Retention of water in an impoundment prior to discharge into wetlands may aid the effectiveness of wetland nutrient removal by stabilizing flow rates and/or equalizing nutrient concentrations.

A drainage project which includes plans to use a wooded swamp as a sheetflow area is in preparation by the Soil Conservation Service (J. Garrett and K. Ballance, Soil Conservation Service, Swanquarter, NC, personal communication). Pumped discharge from part of a 4,000 ha (10,000 ac) diked agricultural area north of Lake Mattamuskeet will be sent into an adjacent gum-cypress swamp of about 110 ha (280 ac) (Figure 35). The discharge will flow over the swamp, reaching the Alligator River after an unknown period of retention. Monitoring of discharge rates and chemical concentrations in water passing through this wetland would provide valuable information on the conditions necessary for effective treatment.

Overland Flow on Grassed or Vegetated Areas

Overland flow on grassed areas is effective for removal of nitrogen on waterlogged and low permeability soils (Peters and Lee 1978). This method has been used successfully to treat food processing wastewater from several Campbell Soup Company plants (Hunt et al. 1976). An aerobic zone needs to be maintained near the soil surface which nitrifies ammonium to nitrate. The nitrate moves down into the reduced subsurface soil where it is denitrified to gaseous forms of nitrogen which escape to the atmosphere. Vegetation takes up nitrogen as well. Phosphorus removal may be only moderate, however, because of limited contact between phosphorus in runoff and the soil below.

Extensive research in overland flow treatment is being conducted by the U.S. Army Engineer Waterways Experiment Station near Vicksburg, Mississippi. Results from greenhouse and field experiments indicate that, depending on the season, total nitrogen (including organic, NO_3^{-1} and NH_4^{+1} forms) was reduced 78-90% when wastewater was applied at a rate of 1.27 cm over a six-hour period. Phosphorus levels were reduced 45% (in winter) to 68% (in spring). Higher application rates resulted in less effective assimilation of both nutrients (Peters and Lee 1978). Runoff from overland flow areas could be caught in detention ponds and used for irrigation during periods of drought.

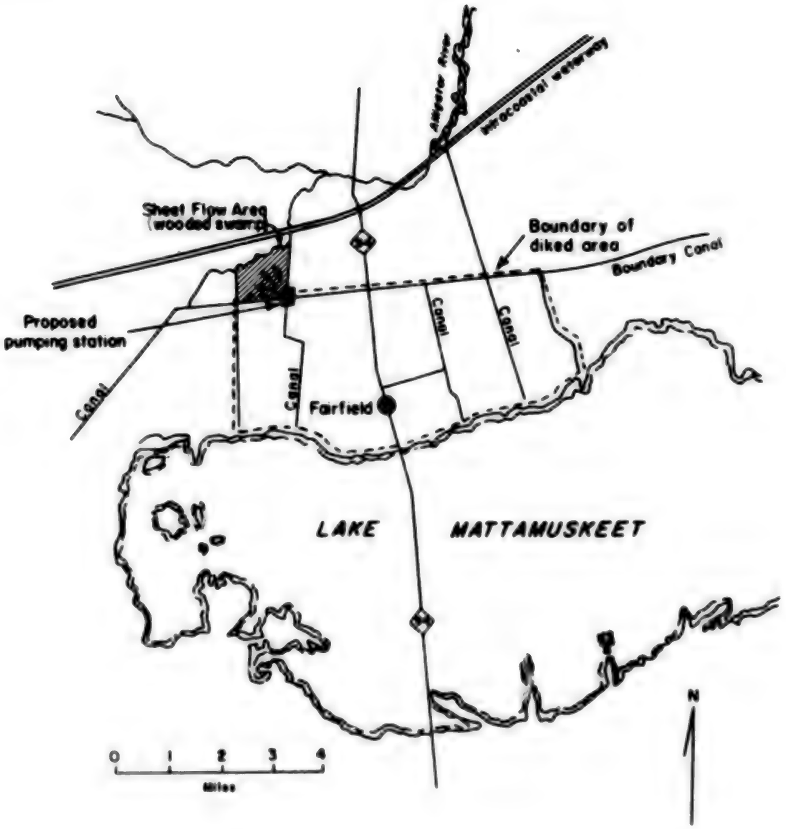

Figure 35. Plans for discharge of pumped agricultural drainage by sheetflow through a wooded swamp (K. Ballance, personal communication).

Detention Ponds

Impoundments, sized to accommodate a given volume of runoff, could be constructed at intersections of collector ditches and canals (see Forest Land Ownership and Management, Figure 28). Series arrangements would allow maximum detention while providing control of water depth for both nutrient treatment and fire protection. Flashboard risers (Figure 26) or other control devices could be used between ponds. Eventually, sedimentation would require that ponds be cleaned out or maintained as marshes. Although ponds would provide some nutrient removal (probably mainly via sedimentation, but also through denitrification), additional treatment by sheetflow through wetlands would be desirable and might be enhanced by "pretreatment" in holding ponds (Figure 36).

Alternatively, a series of impoundments based on a system in use at Mattamuskeet National Wildlife Refuge might serve as holding and treatment areas for runoff and simultaneously provide food and habitat for wildlife (Figure 37). In this system, three impoundments hold differing water levels for storage, wildlife management, and nutrient removal. In successive years water levels could be rotated to allow rejuvenation and eliminate pest species. Outflow could be provided from any of the impoundments through a wooded "buffer zone" to a creek or canal.

In impoundments available to wildlife, levels of pesticides in water and biota would need to be carefully monitored. However, any natural system being used as a treatment area for agricultural runoff would potentially entail some risk of pesticide contamination and accumulation. Without study of specific situations, not enough is known about pesticide delivery, possible degradation products, and effects to define the kind or degree of hazard. Uncertainties of this type underscore the need for detailed pilot studies before such treatment systems are recommended for general use.

Companion Areas of Cropland, Pasture, and Forest

Nutrient-rich runoff from cropland could be discharged into pastures or meadows that require less strict drainage and from these into mid-rotation managed forests where water is effectively removed by evapotranspiration in the warm season. Impoundments in or near forests could provide additional treatment of water as well as fire protection. Under this kind of system, nutrients in runoff would serve as a subsidy to the next area rather than becoming waste products of potential hazard to estuaries. Various combinations and configurations of land use would be possible depending on local situations; such systems would lend themselves to cooperative management by adjoining land owners.

Ecologically Diverse Runoff Treatment

Parts of large farms could be set aside for construction of artificial "meadow-marsh-pond" systems. Diking of the pond may be necessary and an overflow outlet or pump may be provided to a discharge canal. Retention and removal of nutrients in water may be enhanced by sequential passage of

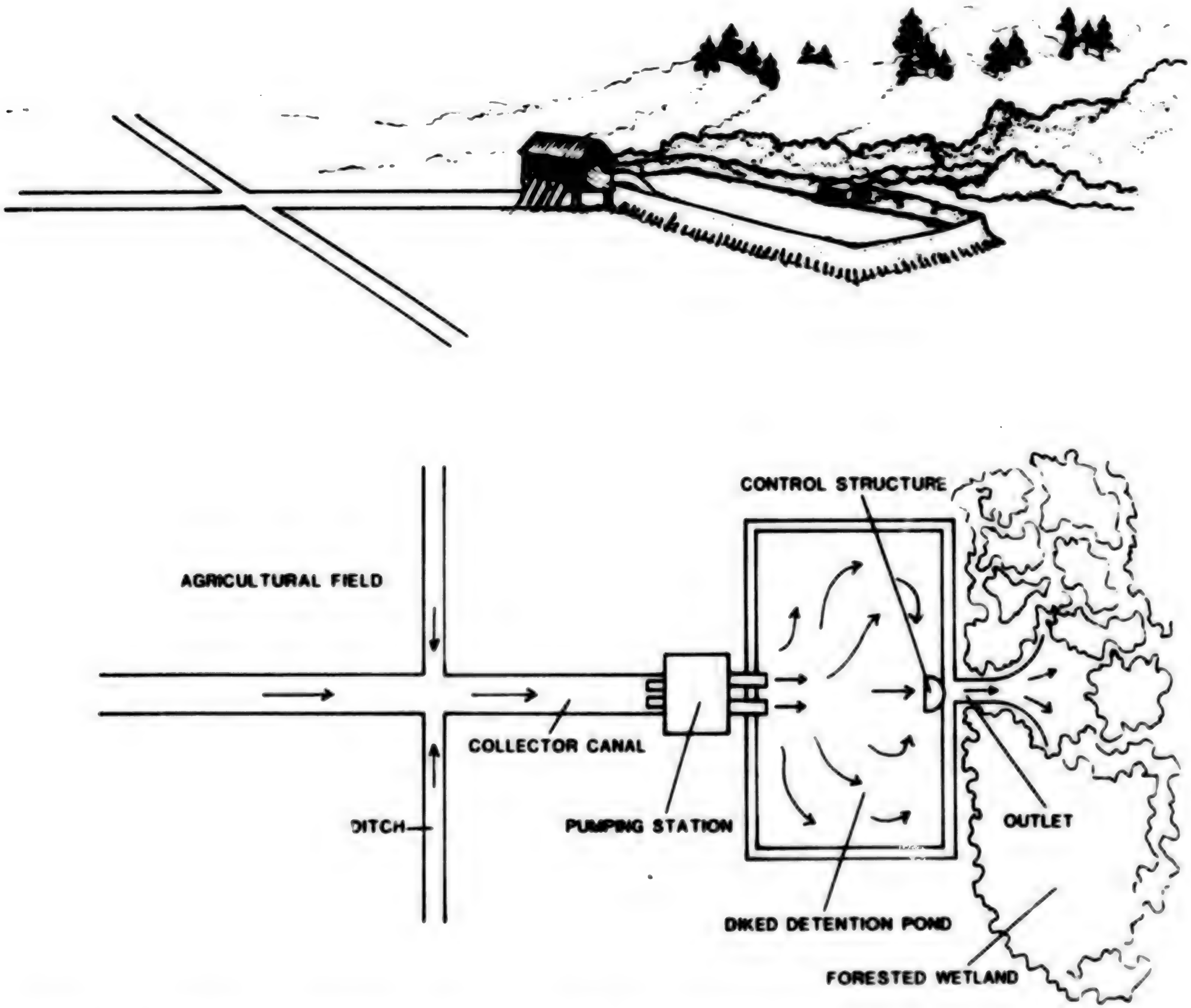

Figure 36. Diagram of impoundment used for storage and treatment of agricultural drainage prior to discharge into a forested wetland.

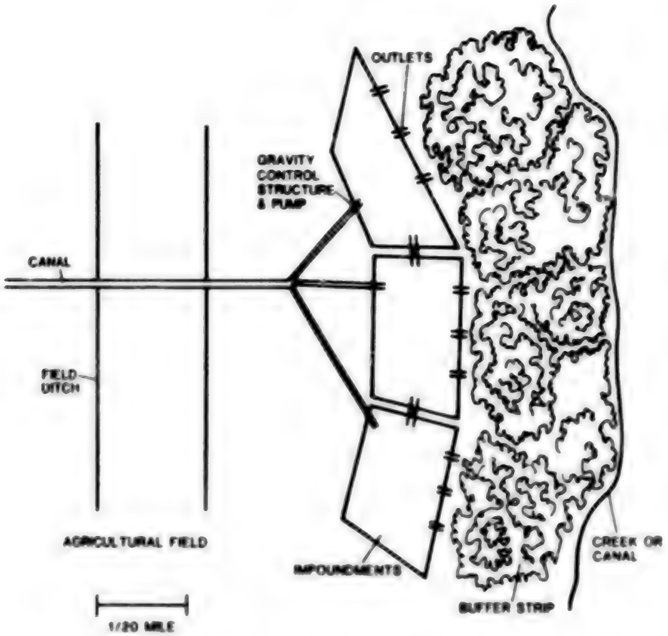

Figure 37. System of impoundments with rotating water level control and outflow through a wooded buffer strip. The system would combine retention and treatment of runoff with wildlife habitat.

runoff through several components. This may be accomplished by allowing runoff to flow from an artificial marsh into a pond, or by passage first through meadows followed by marsh and pond (Figure 38). A different biological system with its own pattern of assimilation and treatment is established in each component of the series. The components first receiving runoff enhance efficiency of succeeding areas, apparently by providing a buffering effect (Blumer 1978).

A pilot project using this concept has been carried out successfully for four years in treatment of sewage effluent on Long Island, N.Y. (Small 1978). Similar plans have also been proposed for use with agricultural runoff in the Kissimmee basin of Florida. About 12% of the total farmland drainage area was used to construct an artificial marsh-pond combination in the Long Island System. In pocosin areas, the pond could be impounded by a levee several feet high and the surrounding marsh allowed to grow up in native aquatic plants (Figure 38). Since the effectiveness of the design depends on harvest and removal of vegetation from the area, these plants would preferably be herbaceous. Water from the pond could be used for irrigating surrounding farmland as well as for fire protection. Concentrations of nitrogen in the effluent from the Long Island pilot project were reduced by 62-79%, although expected reductions would vary with geographic area and type of vegetation. Reduction of phosphorus was about 80%, dependent on regular washing down of the irrigated area to avoid peaks which would overload the system, as well as on regular harvest and transport of aquatic vegetation from the pond watershed. A large farm might be subdivided into several units of manageable size (165 acres was used in the pilot project), each with its own marsh/pond combination.

Changes in Land Use

In certain critical areas the only feasible alternative to problems of water pollution may be change to a less intensive land use. This may mean a change to forested land or pasture from row crops, sometimes accompanied by a decreased economic return to the landowner. However, an individual or firm considering the large investment necessary for developing cropland, might, for example, compare this with the costs of managing Atlantic white cedar forests which are well adapted to poorly drained soils and have high market value. Judicious management and planting of new areas in white cedar or other species could reduce the area of land cleared for crops and still provide economic return similar to more intensive row crop systems.

Summary

1. On-site agricultural best management practices (BMPs) can be of benefit in the control of runoff and sediment, nutrient and pesticide delivery from developed pocosins to estuaries. These BMPs include soil nutrient tests, proper fertilization rates and timing of applications, appropriate seasonal control of water level, limitation of aerial pesticide applications, use of integrated pest management methods, and use of no-till methods and vegetated border strips. Cooperation among public agencies, corporate interests, individual landowners and lease operators will be necessary for the selection and development of appropriate management methods.

2. Water contamination from commercial forest land in pocosin areas can be minimized by management practices such as limitation of road construction and use of vegetated buffer strips along roads and waterways in which disturbance

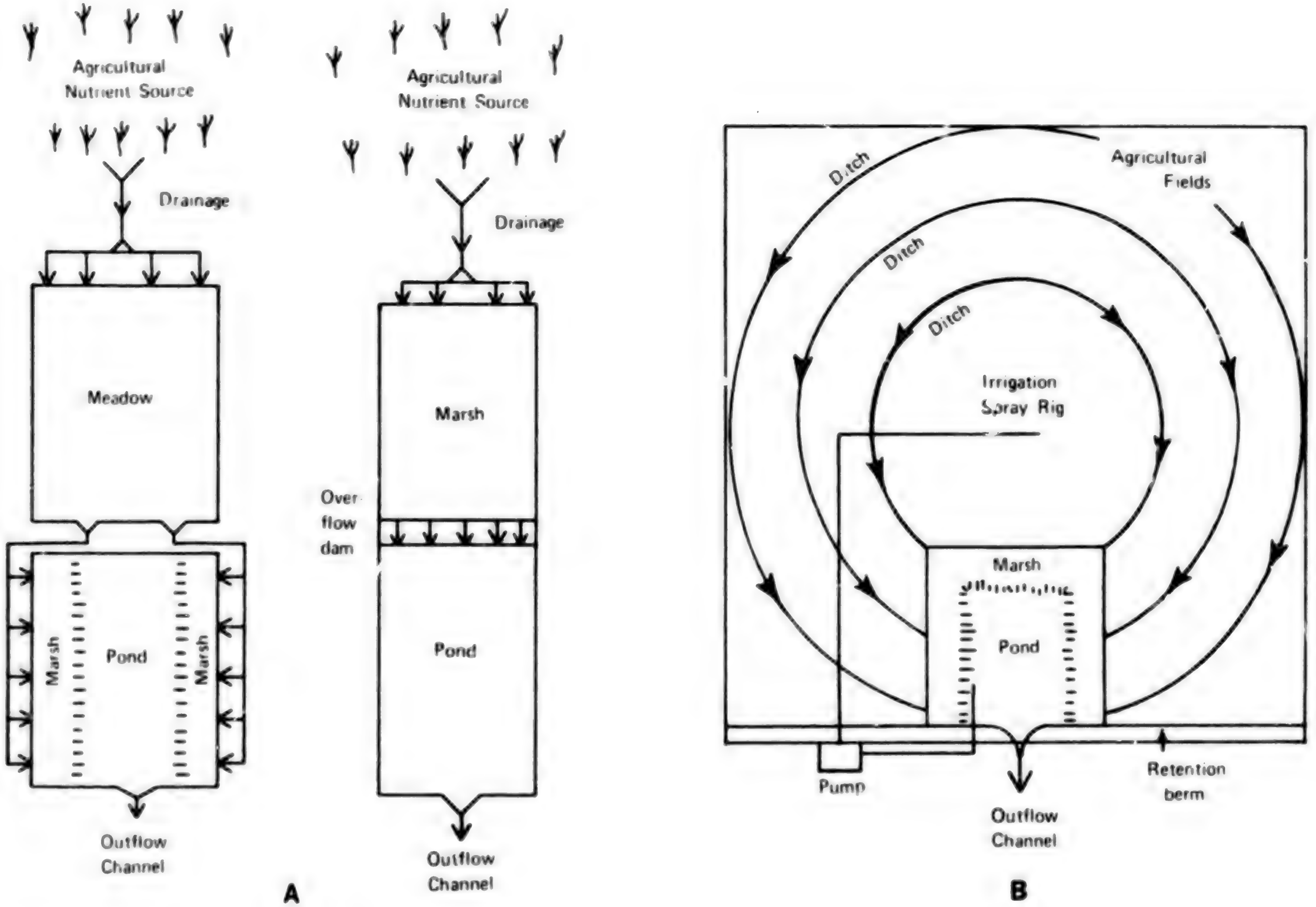

Figure 38. Multi-component runoff treatment systems: (A) marsh/pond and meadow/marsh/pond series systems (from Blumer 1978), (B) a system providing for irrigation of cropland supplying runoff. Marsh/pond area = 12% of total land area (from Small 1978).

and introduction of contaminants are avoided. Pesticide use in forests should be limited to precise specific applications, avoiding widespread aerial application. Programs of landowner education by public agencies, particularly in timber harvest arrangements, and expansion of economic incentives through such programs as the Landowner Assistance Program may be useful in implementation of practices to maintain water quality.

3. On-the-land detention and treatment of runoff from agricultural operations, a practice which has been recommended for areas with similar water quality concerns, should be considered for use in pocosin regions. Detention may be accomplished by impoundments, marsh-pond systems, overland flow areas, spatial arrangements of land uses, and use of wetlands as filter areas. The need for sizable land areas for runoff detention is implicit in the nature of land treatment, which involves slowly-occurring processes. Proposals summarized in this report may require that a significant fraction of total land area be designated for runoff treatment, since the volume of water discharged from an area of cropland is equal to the volume of water delivered to a detention/treatment area. In other words, one centimeter (0.4 in) of runoff from 300 ha (740 ac) of cropland is equivalent to 30 centimeters (12 in) of water on 10 ha (25 ac) of treatment area. If water depth exceeds the treatment capacity of an area, for example a swamp forest, or threatens vegetation survival, a larger area would be needed.

4. Planning from a regional viewpoint is an important approach to maintenance of estuarine water quality in pocosin regions. Pilot projects involving the cooperation of public agencies, academic institutions and private interests will be useful in establishing specific practices. Formation of landowner cooperatives for purposes of planning and cost-sharing of large projects may be desirable. Monitoring of water quality, vegetation, and other ecological impacts should be carried out for any water management project which is implemented in pocosin regions.

CHAPTER 10. FISH AND WILDLIFE MANAGEMENT

INTRODUCTION

Wildlife management is an art as well as a science. Good management requires proper manipulation of habitat (food, cover, water), wildlife species, and human needs. A continuing problem for managers of plant and animal communities of reduced size or geographic distribution is a lack of community-specific life history or habitat use data for many important wildlife species. Pocosins are such communities. In order to propose reasonable management options for pocosins and related freshwater wetlands, it has been necessary to adapt many practices recommended for uplands and mine reclamation areas, and other types of wetlands (Yoakum et al. 1980, Gilbert et al. 1981, Nawroot et al. 1982, Ohlsson et al. 1982, and many others). Additionally, there has been some minimal management work published for pocosins. This chapter is divided into three major sections: the first documents current habitat management options for agricultural lands, commercial forest lands, inland water bodies, and natural forest-land refuges; the second adapts generalized habitat management options specifically to pocosins and related freshwater wetlands; and the third provides specific management options for wildlife species or groups of importance in pocosins and related freshwater wetlands.

CURRENT FISH AND WILDLIFE MANAGEMENT PRACTICES

With continuing development of North Carolina's Coastal Plain, pocosins and freshwater wetlands are disappearing at a rapid rate. Developers can reduce losses of wildlife by incorporating effective habitat management practices and by saving some portion of natural land for those species which require it.

Yoakum et al. (1980) define wildlife management as "the science and art which considers the interrelationships between wild animals, habitats, and man." Further, when planning and implementing wildlife management projects, these six principles should be followed:

1. Projects must be justified according to biological needs based on intensive investigation.
2. Proposed practices must be evaluated for their effect on other natural resources and land uses.
3. Projects must be economically practical and should specify if the objective is to maintain, improve, or completely alter the existing habitat character.
4. Improvements as well as mitigation or restoration must simulate natural conditions. Generally, native flora and fauna should be perpetuated.
5. Manipulation projects must be designed to follow natural topographical features as opposed to geometrical squares or strips.
6. Projects must be evaluated at intervals to determine if the objectives have been accomplished.

For pocosins, there are four general land-use types which require specific sets of wildlife management practices. These include: 1) agricultural lands; 2) commercial forest lands; 3) inland water bodies and adjacent habitat areas; and 4) refuge habitat areas. Urban areas, another type, are not considered here.

The four land-use types require different management; however, they need not be geographically separated. All four areas should be interspersed to maximize species abundance and protection. Natural areas should be scattered throughout developed areas.

Agricultural Lands

Conversion to agriculture is one of the major activities affecting North Carolina pocosins and related wetlands. These large clearings can be favorable for some species such as deer, dove, and quail (Monschein 1981); but in order to enhance wildlife, the manager must provide three important habitat requirements--food, cover, and water--in an arrangement accessible to the animal (U.S. Forest Service 1969). Accessibility can be enhanced by corridors; strips of cover providing avenues for wildlife travel (U.S. Forest Service 1969). These can be provided by leaving woody vegetation, or by planting ground cover, and can be done with minimal financial burden.

Food. The most frequently used practice to improve wildlife habitat is to provide food (Yoakum 1971). Food is plentiful on agricultural lands (Trippensee 1948) and the manager need only make it available (Appendices G and H). One practice is to leave strips and odd corners of grain crops or to plant annual and perennial strips for food patches (Trippensee 1948, Monschein 1981). Several well-distributed food patches of 0.4 ha (1 ac) are most effective. One food patch every 16 ha (40 ac) should be considered a minimum. A long, narrow patch is the best shape. Corn and soybeans are excellent grains for fall, winter, and early spring use by wildlife. some other good choices for pocosin lands are winter wheat, rye, sunflower, and millet. For several seasonal needs, planting a mixture has the best effect (Trippensee 1948).

One problem on agricultural lands has been the use of pesticides. Songbirds, game birds, and other animals have all been affected by consuming contaminated plant parts and organisms that have been killed by pesticides on agricultural lands. Therefore, this practice should be carefully evaluated and probably reduced (Barick and Critcher 1975).

Another practice to enhance food production is to leave or plant mast-producing trees and shrubs on field edges (Monschein 1981). A combination of tree species is best, with oaks being the most important. Some other species to include in coastal areas are hickory, gum, Carolina laurel cherry, and ericaceous shrubs (U.S. Forest Service 1969, U.S. Soil Conservation Service 1978). An additional management technique is to rotate crops and allow natural food growth (Monschein 1981).

Cover. Cover is vegetation or other shelter for game. It may be a single plant or a very small area. There are four kinds of cover: escape, loafing, nesting, and roosting (Leopold 1933). Hedgerowing is one practice which provides escape, refuge, and nesting cover in addition to providing travel lanes. Planting of natural low woody vegetation along fence rows, drainage ditches, streams, ponds, food patches, and breeding grounds is one option (Appendix H). In open areas, one 15 m (50 ft) wide strip per 49 to 62 ha (120-150 ac) appears sufficient. Another establishment technique is to plow a strip, and then stagger fence posts with wire strung between them. Bird droppings are laden with viable seed and will result in plantings beneath the fence line almost as fast as ones produced from root stock (Yoakum et al. 1980).

Brushpiles and stump-piles are often used to provide protective cover (Figure 39). When grass, forbs, and vines grow through the brush they add density and permanence to the pile. Brushpiles in modified pocosins are commonly constructed by bulldozer and are either circular with a diameter of 10 to 20 m (33-66 ft) or linear windrows with a width of 10 to 20 m (33-66 ft) and a length equal to that of the cleared field. When fields are being cleared these piles should be only partially burned, retaining as many brushpiles as possible.

Windbreaks are similar to brush piles (Figure 39) but can be established with live or dead materials. They have a dual purpose in the field. They not only provide wildlife cover, but also help prevent wind erosion. The North Carolina Department of Natural Resources and Community Development Peat Mining Task Force (1981) recommended that windbreaks should be 20 m (66 ft) wide extending across cleared areas every 400 m (1300 ft), and if next to a major canal, the tree strip should be left or established on the south or west side. Windbreaks will protect down-wind soil a distance of 10 times their height (U.S. Soil Conservation Service 1978). The best windbreaks are conifers, but deciduous species are occasionally used. If windbreaks are to be used as wildlife travel corridors, they should be 30 m (100 ft) wide.

Like windbreaks, stubble, weeds and other refuse left in the field also serve to control wind erosion and provide cover during the winter months. Stubble should not be burned if wildlife is to be encouraged. Roosting cover should be provided for those species that need it. In modified wetlands of the Southeast, strips of vegetation along drainage ditches and streams will provide cover. It is also possible to construct roosts if necessary (Yoakum et al. 1980).

Nesting cover may be provided naturally or artificially. To improve natural nesting cover, the manager has several choices. Leaving permanent, undisturbed cover along fences, ditchbanks, roadsides, railroad rights-of-way, waste areas, and odd corners will provide nesting cover for grassland or field nesting species. In the Coastal Plain, planting mixtures such as lespedezas, millets, hollies, and cedars should be used. If native grasses are used, mowing, roll-chopping, burning, or grazing will break up dense cover

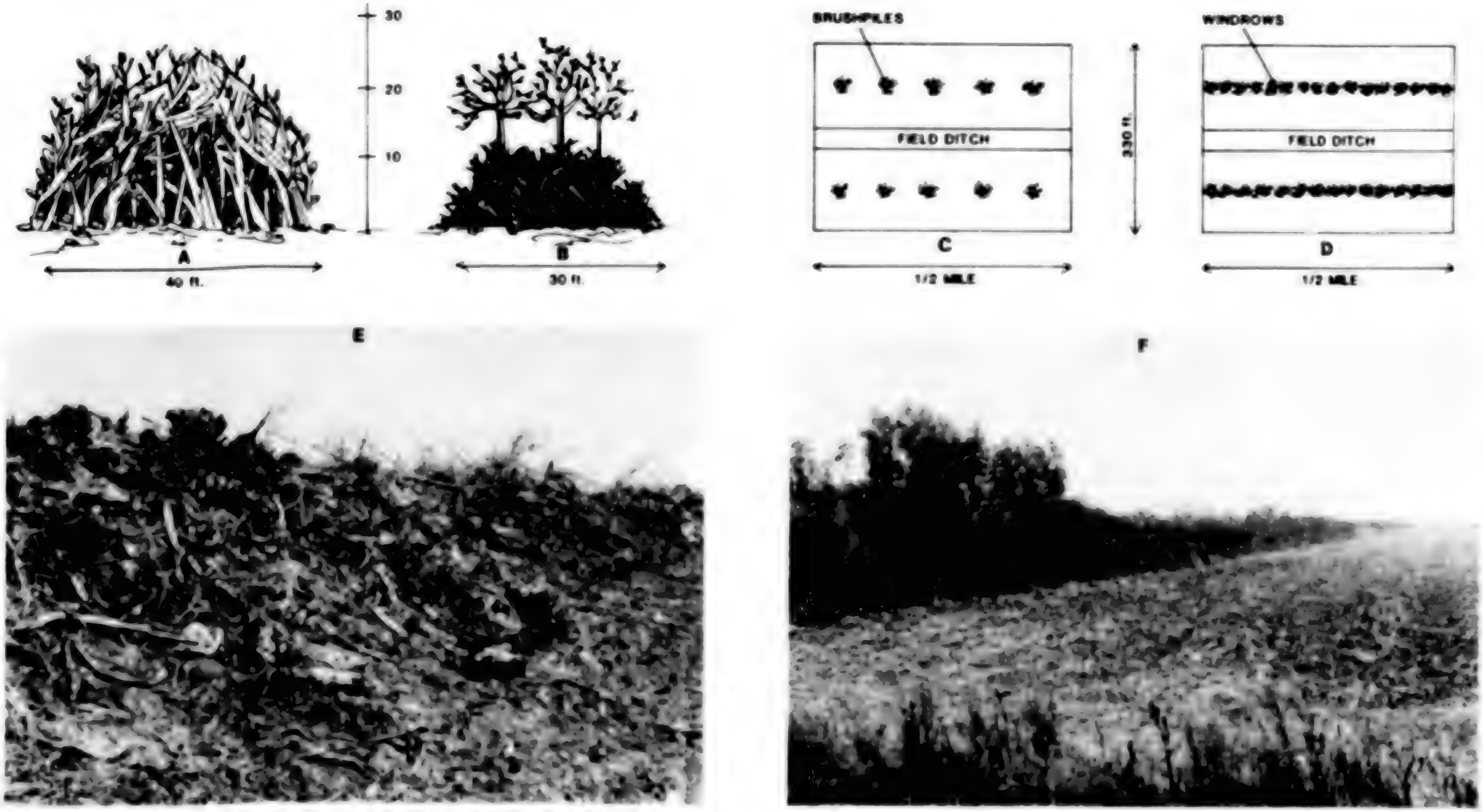

Figure 39. Brushpiles and windrows: (A) unburned brushpile, (B) partially burned brushpile with natural regeneration, (C and D) distribution of brushpiles and windrows in fields, (E) unburned windrow, Hyde County, North Carolina, (F) partially burned and revegetated windrow, Hyde County, North Carolina.

that will eventually develop (Yoakum et al. 1980). For wildlife that require den or nesting trees, wooded areas should be preserved (Yoakum 1971). Den trees will be discussed more thoroughly in a later section on management practices for forest lands; however, den trees are equally important for wildlife on agricultural lands.

Where den trees and other nesting cover cannot be provided naturally, artificial nest structures will suffice (Yoakum 1971). Nest boxes, tires, platforms, baskets, cones, burrows, and ledges are all types of artificial nest structures. The ideal nest structure should attract maximum use, be durable with little maintenance required, exclude predators, be inexpensive, and be easily constructed and erected (U.S. Forest Service 1969). There are many styles and varieties which are suitable as long as they meet the requirements of the target species (U.S. Forest Service 1969, Yoakum 1971, Collins and Landry 1977, Yoakum et al. 1980).

The preceding references provide detailed plans for making housing structures of benefit to waterfowl, perching birds, squirrels, and other important wildlife species.

Examples of such structures are given in Figures 40, 41, and 42.

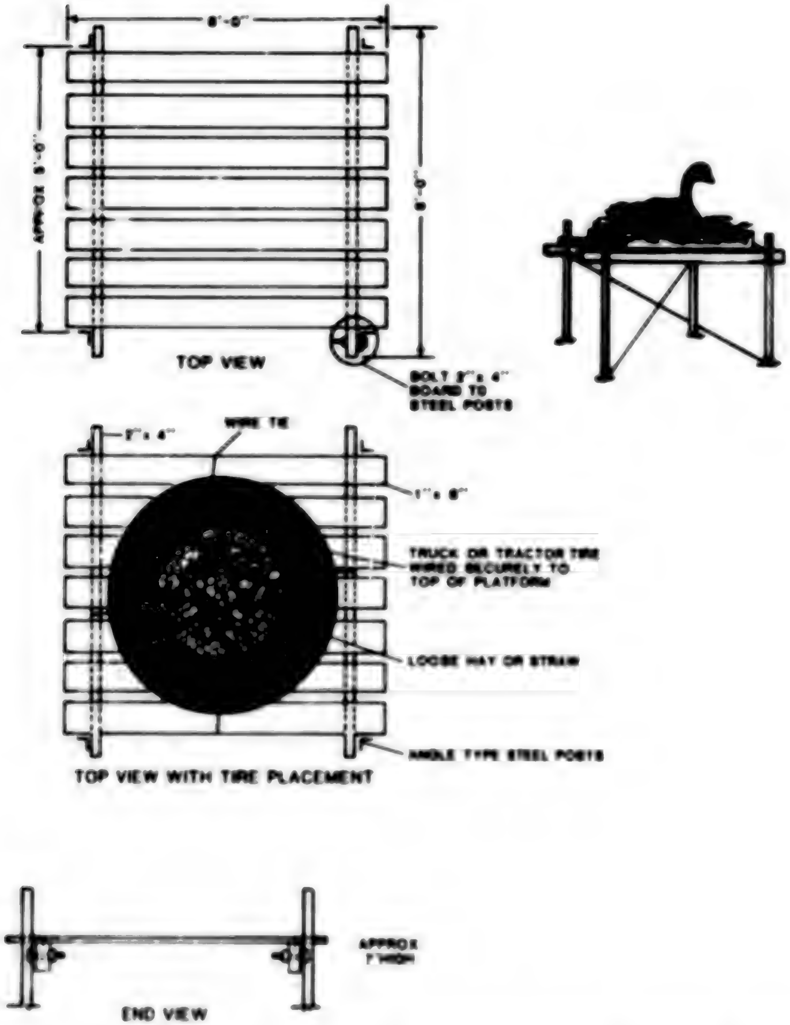
8'-0"
APPROX 5'-0"
6'-0"
TOP VIEW
BOLT 2" x 4" BOARD TO STEEL POSTS
WIRE TIE
2" x 4"
1" x 6"
TRUCK OR TRACTOR TIRE WIRED SECURELY TO TOP OF PLATFORM
LOOSE HAY OR STRAW
ANGLE TYPE STEEL POSTS
TOP VIEW WITH TIRE PLACEMENT
APPROX 7' HIGH
END VIEW

Figure 40. Nest platform for Canada geese (adapted from Yoakum et al. 1980).

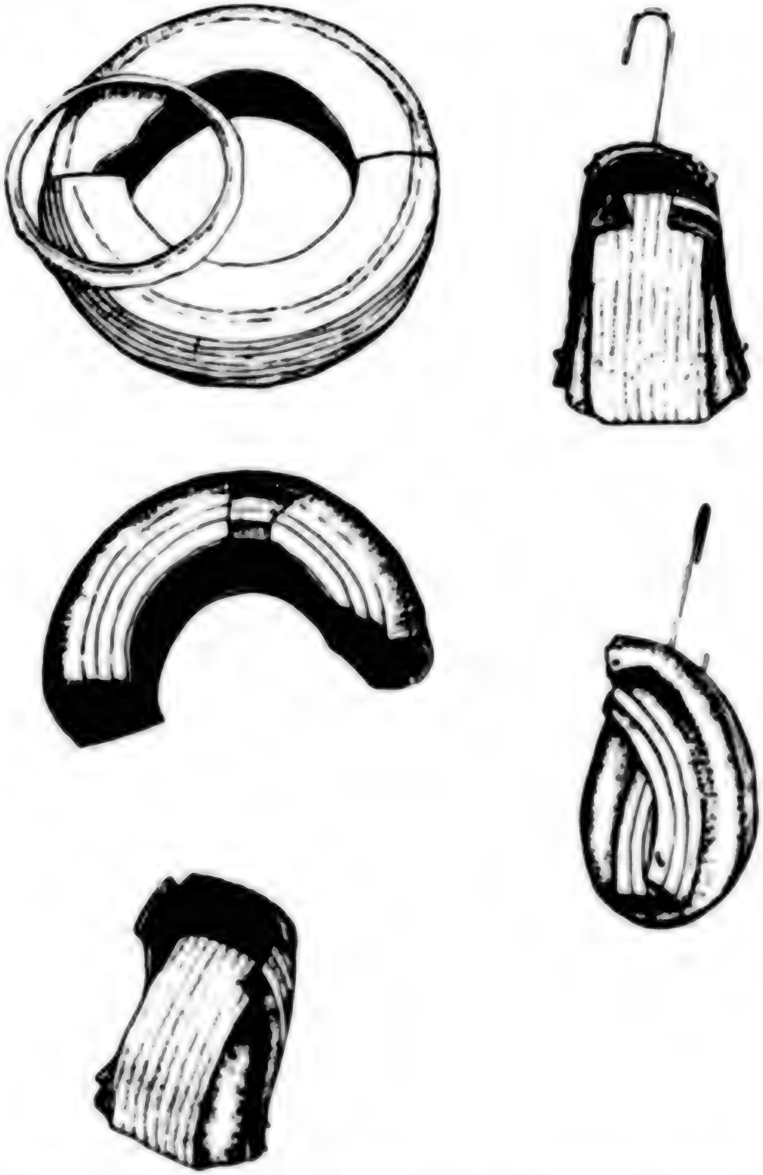

Figure 41. Nest box for squirrels constructed from an old tire (adapted from Yoakum et al. 1980).

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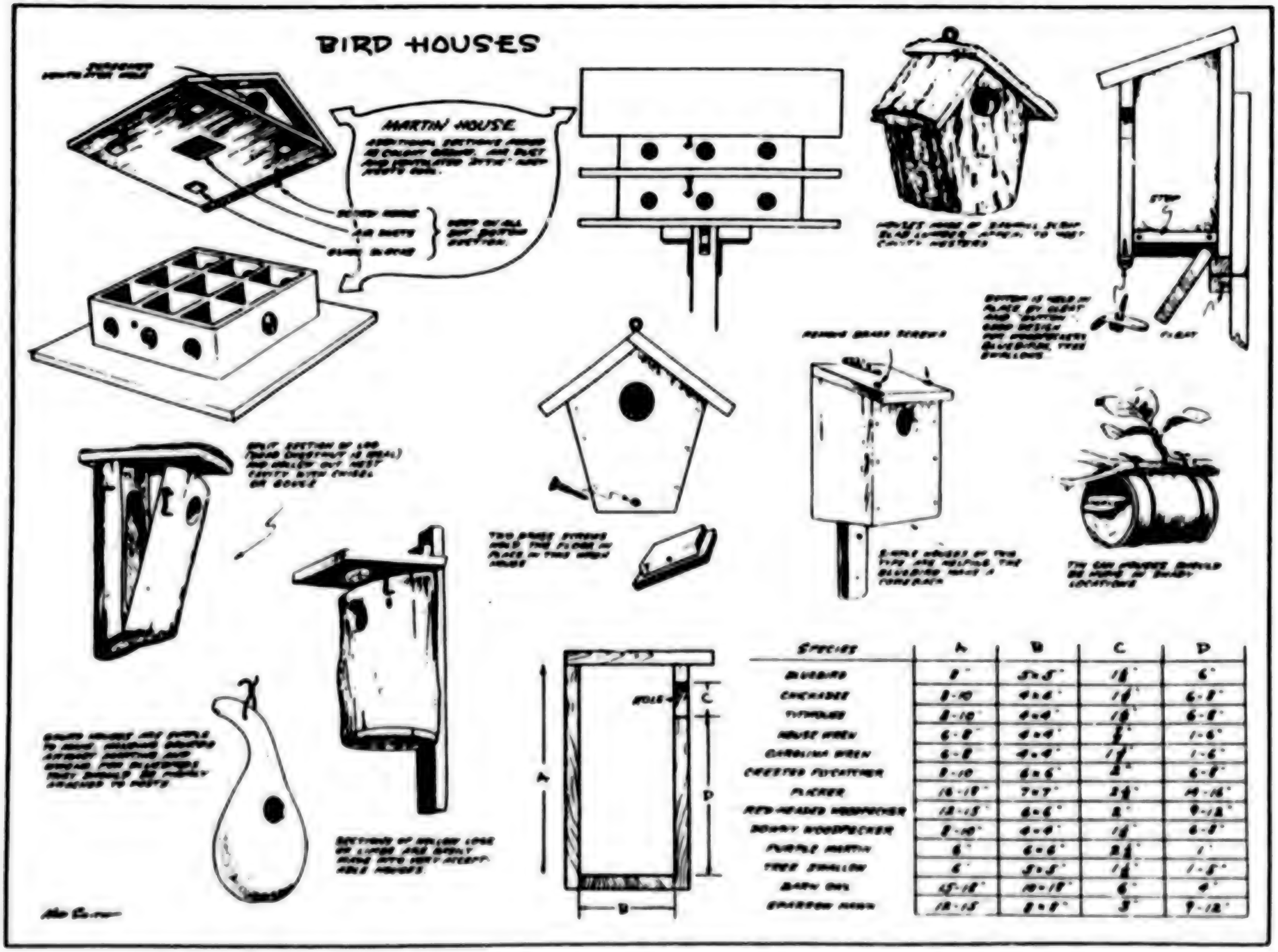

Species	A	B	C	D
Bluebird	8"	5x5"	1½"	6"
Chickadee	8-10	4x4"	1⅛"	6-8"
Titmouse	8-10"	4x4"	1¼"	6-8"
House Wren	6-8"	4x4"	[illegible]	1-6"
Carolina Wren	6-8	4x4"	1½"	1-6"
Crested Flycatcher	8-10	6x6"	2"	6-8"
Flicker	16-18"	7x7"	2½"	14-16"
Red-headed Woodpecker	12-15"	6x6"	2"	9-12"
Downy Woodpecker	8-10"	4x4"	1¼"	6-8"
Purple Martin	6"	6x6"	2½"	1"
Tree Swallow	6"	5x5"	1½"	1-5"
Barn Owl	15-18"	10x18"	6"	4"
Sparrow Hawk	12-15	8x8"	3"	9-12"

Figure 42. Nest boxes for woodpeckers and passerine birds (adapted from Yoakum et al. 1980).

Water. A third way to improve habitat is to ensure availability of water. In most areas of the Coastal Plain of North Carolina where wetlands are being developed for agriculture, water is seldom a problem for most species. Numerous drainage ditches, impoundments, and natural water bodies make water easily available. However, ditch and soil water levels may become low during prolonged drought, and can be effectively controlled by properly installed weir (canal gate) systems or flashboard risers (Burger 1973).

Commercial Forest Lands

Forest lands are undergoing major development on the Coastal Plain of North Carolina, and since nearly two-thirds of North Carolina is covered by forests, they constitute the largest blocks of wildlife habitat in the state. In forests where production and harvest of timber is the main objective, dense stands of pine in large contiguous blocks with little or no understory of hardwoods, shrubs, and vines may prevail. Under these conditions, the forest becomes unproductive for wildlife. Cover and water are generally available, but food is often in short supply. Thus, wildlife density and diversity are often reduced. Generally, however, timber production and harvest can be compatible with wildlife, especially where proper management practices are employed (Barick and Critcher 1975). As with well-managed agricultural lands, where food, cover, and water are accessible, wildlife will flourish. Some of the important forest wildlife game include white-tailed deer, squirrel, bear, woodcock, bobwhite quail, furbearers, and waterfowl which winter or stop during migration. Non-game birds which use forests include owls, hawks, and passerine birds. Furbearers which inhabit forested areas are bobcat, fox, raccoon, opossum, beaver, muskrat, otter, and mink. Also, small mammals use the forest as a home (Trippensee 1948).

Food. To maximize production of understory plants for browse, fruit, and foliage production, several practices may be considered. Overstory pine density is inversely related to understory food production; therefore, stands should be periodically thinned for good understory mast yields. Prescribed burning is highly recommended for both timber and wildlife. Not only does it improve yield and quality of herbage benefiting wildlife, but also reduces fire hazard, reduces brown spot disease (*Scirrhia acicola*) of longleaf pine, restricts growth of unwanted hardwoods, and reduces slash and weeds, making seeding and planting of trees easier. Care should be taken to burn at 3-5 year intervals to help keep foods accessible to wildlife. Summer burning should be avoided because it may eliminate understory species preferred for fruit and forage, and may destroy quail and other wildlife nests (U.S. Forest Service 1971).

Clearcutting is another practice which can be compatible with wildlife. Barick and Critcher (1975) suggest that it be done in small units of about 20 ha (50 ac) or less to maintain diversity of age classes in the forest. In practice, larger blocks up to 100 ha (250 ac) are common (Meyers and Johnson 1978). Yoakum et al. (1980) suggest several narrow 8 ha (20 ac) clear-cuts less than 150 m (500 ft) wide. Robinson and Barkalow (1979) agree, suggesting both the age-class distribution in the regenerated forest and the clearcutting will benefit bobwhite quail. Irregular block shapes are recommended where feasible. Clearcutting will increase edge, create open areas, and stimulate growth of additional food plants (Robinson and Barkalow 1979).

Manipulation practices include spraying to reduce undesirable plants; seeding; and stumping and burning to increase openings, encourage release from competition by other plants, and reduce numbers of competing plants (Yoakum 1971). Browse production in these areas can be increased through rejuvenation and planting. The U.S. Forest Service (1969) suggests leaving and encouraging stands of mixed species and hardwood stands to help increase mast production in forests. Two other methods to increase mast production are propagation or direct planting and release which involves removing competitive plants by fire, herbicides, or cutting (Yoakum 1971).

Existing and former fire lanes and can be fertilized and seeded to lespedeza and other food plants (Appendices G and H), and 0.4 to 2.0 ha (1-5 ac) food plots can be established for wildlife (Forbes and Meyer 1956). Prescribed burning within these strips and plots will also increase habitat diversity, provide edge (Forbes and Meyer 1956), provide spring greenery, and stimulate fruit production by shrubs. These openings will increase wildlife population levels by improving local habitat diversity (U.S. Forest Service 1969).

Finally, for some species such as red-cockaded woodpecker, managed forests may provide necessary foraging habitat. A good foraging stand for the woodpecker would consist of pines of 23 cm (9 in) and larger diameter at breast height (DBH) covering 40 to 80 ha (100-200 ac) (Hooper et al. 1980, Jackson et al. undated).

Cover. The practice of encouraging openings with dense brushy vegetation will satisfy cover requirements as well as food requirements for many wildlife species of the southeastern Coastal Plain. Practices such as planting, release, and regeneration used to enhance production in these areas were discussed in the previous section on food. Figure 43 illustrates a managed forest opening.

The same types of cover needed for wildlife on agricultural land (escape, loafing, nesting, and roosting) are needed on forest land. Areas of cover should be connected by access corriders. These can be gullies, hedgerows, canal banks, natural water courses, strips of woody vegetation, windrows, and others. In areas that have been recently clearcut or burned, corridors for migrating deer should be left or provided. General purpose corridors for both large and small wildlife species should be 30 m (100 ft) in width (U.S. Forest Service 1969).

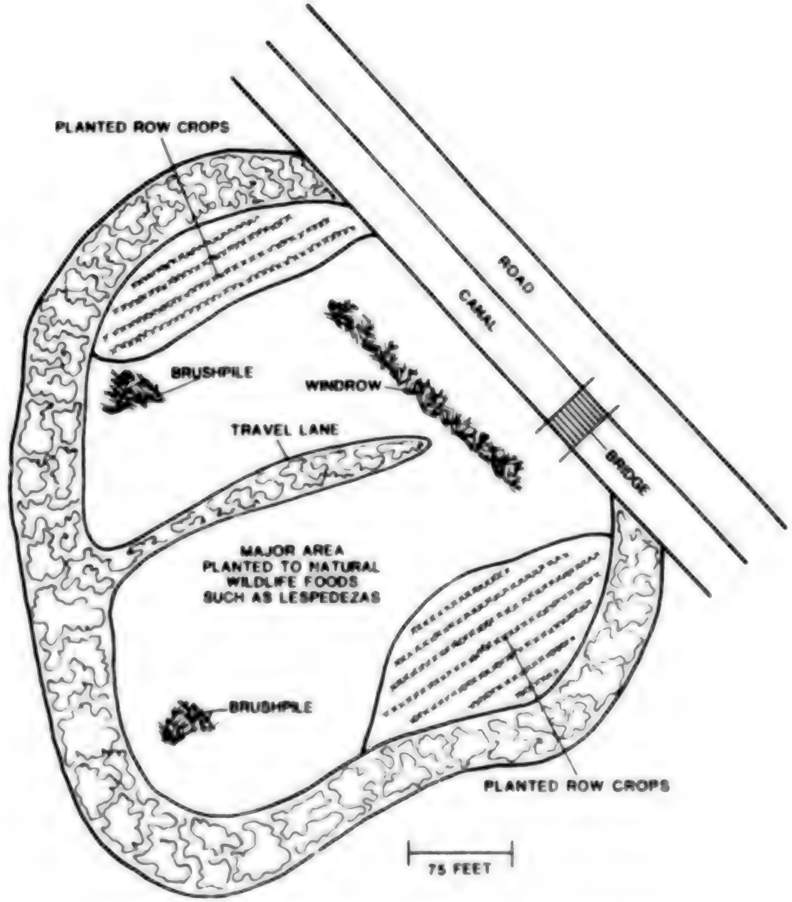

Figure 43. A managed clearing in pocosin.

On forest edges and in forest openings brushpiles, hedgerows, and border plantings can provide escape, refuge and nesting cover, and travel lanes. Brushpiles (stump-piles) can be a by-product of timber harvest, timber stand improvement, preparation of land for agriculture, or release cutting. Vegetative islands are another means of providing shelter, escape cover, nesting, breeding, and other cover as well as food in open areas. They may be natural or planted vegetation (U.S. Forest Service 1969). The cost of creating hedgerows and border plantings around forests is low to moderate, and both provide excellent "edge," cover, and food improvement on areas that might be unproductive of wildlife. In addition, they benefit the stand by reducing wind velocity and thus drying (Forbes and Meyer 1956).

A practice related to clearcutting is managing for small blocks of different ages. The more diverse the blocks, the more continuous the supply of both wood and wildlife (Trippensee 1948). Small clearcuts provide small food-producing units and various age classes of pine (Barick and Critcher 1975). In the Southeast, these mixed-age management blocks may particularly benefit bear (Trippensee 1948) and red-cockaded woodpeckers. For an adequate number of cavity trees for red-cockaded woodpecker, minimum rotation age of 100 years for longleaf pine and 70 years for other pines is necessary. If this is not possible, then small scattered stands of older pines will benefit red-cockaded woodpeckers by providing replacement cavity trees at later dates (Jackson et al., undated). Robinson and Barkalow (1979) also point out that the best program for bobwhite quail is good tree age-class distributions among multiple management blocks. Such management is good wildlife practice in general when coniferous monocultures are involved.

One of the most important components of nesting cover in forests is cavity or den trees. Many game species, furbearers, small mammals, and a large number of bird species require den trees or some similar substitute cover. Besides nesting cover, den trees also provide cover for brood-rearing, hibernation, shelter from the elements, and seclusion from predators (U.S. Forest Service 1969). Any trees found with the capacity to provide dens should be marked and saved during timber cutting if feasible (Trefethen 1964, Forbes and Meyer 1956).

Wood ducks are a good example of a species that depends on natural tree cavities. They have high aesthetic value (Jahn 1966) and are the South's only widely distributed breeding species of waterfowl (Hankla and Carter 1966). These ducks require a hollow cavity tree (Kortright 1967, Burger 1973). For nesting, wood ducks use bald cypress, sycamore and red maple in bottomlands and oaks in uplands (Hansen 1966). The red-cockaded woodpecker is another species that requires a den tree. Cavity trees are living pines with red-heart disease (Fomes pini) and are over 60 years old (Jackson et al., undated). Cavities have been found in all common species of southern pines (Hooper et al. 1980).

Nest boxes have been very successful for wood ducks and other wildlife. In one project, 64% of 6,000 wood duck boxes produced broods averaging 11 ducklings each (Trefethen 1964). Burger (1973) discusses different types and placement of wood duck nest boxes. Nest boxes are also useful for squirrels and various non-game species such as bluebirds, owls, and kestrels. Other artificial nesting structures include platforms, baskets, cones, burrows, and ledges (Yoakum et al. 1980).

Water. As with agricultural areas, water is usually not a major problem for most wildlife species in coastal forest lands. Ditching is common on these lands, and they provide suitable water access in most cases. Ditches will be discussed in the section on inland water bodies and adjacent habitat. Here, comments will be confined to cypress swamps and impoundments.

In cypress swamps, stand density influences total mast production. A stand density which allows for full crown development produces the most abundant mast crop. Therefore, thinning and selective cutting can sometimes enhance the area for many wildlife species. To minimize poor bole characteristics, pruning is recommended for trees that will be harvested (Brakhage 1966). Almost all of the tree species in a cypress swamp have been found to accommodate wildlife, so some trees (cypress, gums, and oaks) should be left to late maturity (Hansen 1966). In response to lower crown density, supplemental understory food plants such as lespedeza, cane, greenbriar, hollies, and smartweed should grow. Two sources of information pertaining to plantings for the southeastern United States are Atlantic Waterfowl Council (1972) and U.S. Soil Conservation Service (1978).

In addition to insuring food production, it may be necessary to create resting sites. Ridges and islands can be constructed with a bulldozer (Yoakum et al. 1980). Floating islands made of green logs with rough mitered corners made by a chainsaw and fastened with lag screws can be anchored and landscaped with grass or willow to provide shade and protection (Shomon et al. 1966). Although waterfowl are the principal target species, squirrel, deer, quail, raccoon, other furbearers, and many species of non-game mammals, birds, reptiles, and amphibians will benefit. For information on other types of man-made islands that have been constructed, see Landin (1978). For information on water level control, see Yoakum et al. (1980).

Impoundments can improve forests for wildlife. They are generally created in conjunction with ditch systems on lands managed for timber in order to maintain large water supplies for fire suppression (Figure 28). Their management for wildlife will be discussed in the section on inland water bodies and adjacent habitat.

Natural Forest-Land Refuges

Many wildlife species do well in areas that have been developed for farming or commercial forestry. The species that do well around farm and forest edges are generally popular game species such as deer and quail which have high public visibility. An often ignored fact is that there are many species that are detrimentally affected by agricultural or commercial forest development because they do not make use of edge habitat (Matthiae and Stearns 1981, Whitcomb et al. 1981). Examples in the southeast would be mountain lion, bear, many passerine birds, and many reptiles and amphibians (Braswell and Wiley 1982). If these species are to be maintained on a regional basis, then acceptable natural habitat must be preserved as natural forest-land refuges. While the prime mission of any forest-land refuge must be to preserve natural habitat, there are several management practices that may enhance their quality and habitat diversity. The following section will discuss these practices.

Preservation and maintenance of natural habitat. The primary function of a natural forest-land refuge is to conserve natural habitat, but the task is seldom simple. Important plant communities are often successional or adapted to random catastrophic events such as fire or inundation. Fire plays an important role in the development and maintenance of pocosin (Christensen et al. 1981) as well as several other related communities such as savannah and Atlantic white cedar swamp forest. Inundation is important to swamp forest and marsh. To maintain these communities on forest-land refuges, it is necessary to mimic periodic disturbances if they no longer occur naturally. Fire can be mimicked by prescribed burning, or roll-chopping, with or without burning (Tom Monschein, personal communication). Both practices reduce understory density and biomass, while increasing the percentage of biomass available for wildlife food. Impoundment water levels on forest-land refuges are often regulated to maintain established marsh communities for waterfowl (Tom Monschein, personal communication).

Some important natural communities are successional stages which will naturally disappear with time. The easiest way to maintain these is to have multiple management plots arranged in a rotational scheme, so that all successional types will be present at all times (Harris et al. 1982). When a rotational scheme is planned, care must be taken to insure proper juxtaposition of successional types for maximum benefit to wildlife (Harris and Kangas 1979, Harris and Marion 1982, Harris et al. 1982).

Modification of natural habitat within forest-land refuges. Often natural forest-land refuges are operated according to multiple-use principles (see Regional Management section). Here, compromise decisions must be made that provide the greatest benefit to the largest number of involved interests (wildlife, forestry, hunting, fishing, recreation, etc.). Many multiple-use decisions require modification of natural wildlife habitat. The most common modifications are discussed below.

If timber is harvested in small blocks that make up a small percentage of the total area of a natural forest-land refuge, the logged areas may be converted into clearings for wildlife (Tom Monschein, personal communication). These create edge that benefits game species such as deer, quail, and dove. Clearings can be planted to crops or natural food, be located in association with canals, and have brush piles or nesting structures as does agricultural or commercial forest edge.

If the land is low and there is a source of water, clearings may be converted into impoundments. This practice is common and successful in eastern North Carolina (Monschein 1980).

In forest-land refuges where timber operations are incorporated into the management plan, the entire refuge may be divided into management blocks and harvested over a period of years. Much attention should be paid to relative positioning of cut, uncut, and intermediate rotational blocks for the benefit of wildlife (Harris et al. 1982). Also, natural patterns of land drainage and topography should be incorporated into management plans (Harris and Kangas 1979).

If hunting is encouraged, modifications such as impoundments, hunter-trails and access roads will have to be placed through natural habitat. Loss of vegetation is minimal, and increased use and awareness of the forest-land refuge by hunters more than offsets negative effects. These types of modifications have been very successful in eastern North Carolina (Charles French, North Carolina Wildlife Resources Commission, Holley Shelter Wildlife Refuge, personal communication).

Rare and endangered species. If a refuge contains habitat supporting a regionally or nationally rare or endangered species, then that habitat may be set aside as a unit to be managed chiefly for the species in question. Examples of species in eastern North Carolina are black bear, red-cockaded woodpeckers, and alligator. Endangered species management is practiced, at least informally, on several eastern North Carolina refuges (Tom Monschein, Charles French, personal communication).

Inland Water Bodies and Adjacent Habitat

Due to their abundance and use by wildlife, water areas are of major importance on the Coastal Plain. This section concerns man-made water areas and natural water courses structurally modified by channelization. Other natural water areas such as lakes, unmodified streams, tidal marshes, and estuaries are discussed in other portions of this document.

Drainage areas. Wilson (1962) estimated about 1.8 million km (1.1 million mi) of ditches draining the 41-county coastal plain region of North Carolina. Since 1962, drainage and development have increased at a tremendous rate (Figures 1 and 2). In many cases, this drainage is detrimental to both timber and wildlife production due to lowered water tables and resultant forest fires (Wilson 1962). In addition, where streams have been channelized for more efficient drainage, habitat for fish and wildlife has been reduced (Nunnally and Keller 1979). However, there are exceptions. Ditches may extend range for alligator, muskrat, and mink; and if properly managed, they can provide good habitat for other species (Wilson 1962). If streams are restored instead of channelized, they become significantly more productive and more stable systems, without significantly reducing any wildlife species. Typically, the cost of restoration is one-tenth the cost of channelization (Nunnally and Keller 1979).

The difference between channelizing and restoring streams needs to be clarified. Stream channelization is an operation used most often to control flooding or to drain wetlands for timber production or farming. The methods, which vary with the objective, include: 1) widening, deepening, and straightening; 2) clearing and snagging; 3) diking; and 4) bank stabilization. Stream restoration refers to a process for designing and constructing new channels or maintaining existing stream channels. It is accomplished by removing debris jams and providing fairly uniform cross-sections and gradients while preserving meanders, leaving as many trees as possible along stream banks, and stabilizing banks with vegetation and riprap where necessary. Restoration is typically less costly than channelization, but drains land slightly less efficiently. However, the more effective drainage by channelized streams is counteracted by environmental problems that include: 1) loss of riparian vegetation during construction; 2) sediment disturbance and increased turbidity; 3) increased water temperatures due to loss of shade; 4) decrease in quality of fish habitat due to loss of pools and riffles and loss of protection from high flow velocities during high discharges; 5) increase in bank erosion; 6) decrease in aesthetics; 7) decrease in rate and duration of flooding; and 8) changes in adjacent vegetational communities. Advantages of restoration over channelization include: 1) minimal destruction of vegetation; 2) increased bank stability; 3) decreased frequency of straightening and relocating the stream; and 4) minimal disturbance of the streambed or vegetation and wildlife in adjacent flood plains (Nunnally and Keller 1979). In addition to the concerns noted by Nunnally and Keller (1979), Barick and Critcher (1975) note channelization destroys hardwood swamps which constitute valuable habitat for certain species of wildlife and act as filters which help purify and sometimes hold water before entering streams and estuaries.

To increase wildlife habitat on stream, ditch, and canal banks, forest cover should be maintained, and no more than 25% of the crown cover should be removed at any one time from a 30 m (100 ft) strip along stream borders (Trippensee 1948). Leaving trees and shrubs has several functions: 1) they serve as buffers; 2) they reduce erosion; 3) they provide direct and indirect cover for fish through shading and some undercutting; 4) they lower water temperature through shading; and 5) they offer resting, feeding, and breeding places for wildlife and insects which are a substantial portion of fish diets; and 6) they increase aesthetics (U.S. Forest Service 1969). If the ditches or streams are on land being managed for timber, this strip may still be harvested if the guideline on leaving 75% crown cover is followed. In addition, vegetation with little or no timber value, such as hollies, cane, or greenbrier, should be left (Trippensee 1948).

On areas where plants have been disturbed or destroyed by drainage construction or maintenance, plantings can be used for improvement. Native plantings are best (U.S. Forest Service 1969); see Appendices G and H for appropriate species. Shrubs and trees may be planted in double rows 1.2 m (4 ft) apart when areas are completely devegetated (Trippensee 1948). Large trees (12 m, 40 ft tall) can be transplanted by a spading machine (Ohlsson et al. 1982). Grasses or perennial herbs and shrubs will stabilize stream banks if they are not too steep (U.S. Forest Service 1969). If a ditch is newly-constructed and both banks were cleared of riparian vegetation, Trippensee (1948) suggests leveling the removed soil and planting one side to woody vegetation and the other to herbaceous plants. He encourages using annual grasses as cover crops to help establish clovers, millets, lespedeza, or perennial grasses. The North Carolina Department of Natural Resources and Community Development Peat Mining Task Force (1981) recommends a minimum 1.5 m (5 ft) width for a vegetated strip on each ditch and canal bank. Wider margins are encouraged. These will provide small game habitat as well as sedimentation control (Peat Mining Task Force 1981). If water levels are controlled by dikes, these should also be seeded (Monschein 1981).

Managed ditches and stream banks will increase populations of furbearers, waterfowl (Wilson 1962), and song and game birds (Trippensee 1948). However, large mammals such as deer and bear need a patchwork of large land tracts of at least 8 ha (20 ac) or more. Strips of woody vegetation along ditches and streambanks could be used as corridors between these large tracts. To maximize their use, corridors should be 30 m (100 ft) in width. Within corridors, many of the management practices presented in the sections on agriculture and forestry may be used (brushpiles, artificial nesting structures, thinning for release of mast trees, and others).

Impoundments. In much of the Coastal Plain, furbearers, waterfowl, wading birds, and other species will flourish where impoundments exist. Once established, impoundments can be managed to provide food and cover.

Dikes to create impoundments can be wooden or earthen. In eastern North Carolina, earthen dikes are most economical and are constructed with draglines, backhoes, bulldozers, or tractor-drawn disks (Wilson 1962). Once constructed, water levels can be controlled to manipulate food and cover, reduce growth of emergents, and speed plant decomposition.

Another technique for establishing impoundments is introduction of beaver. Three counties on the Coastal Plain of North Carolina have live-trapped and relocated beaver from overpopulated areas. Animals migrating from Virginia have founded beaver populations in other coastal counties. They can, in instances, provide habitat for waterfowl and furbearers in addition to their own furbearing value (Wilson 1962). The populations should be regulated through annual sustained harvest as they may flood fields and destroy timber and crops (Hair et al. 1979). Also, the lower the number of beaver, the longer the impoundment will provide waterfowl food. Flooding problems can be managed by installing beaver pipes (Laramie 1978, Yoakum et al. 1980).

Once impoundments are created, both food and cover should be provided in and adjacent to them, or be accessible through corridors. Food and cover can be planted or established on banks and earthen dikes in the same ways they were on ditch banks, and in agricultural and forest land. Millets, lespedezas, and native herbs and shrubs are used on the Coastal Plain (Appendices G and H).

Nesting islands, artificial nest structures, and brushpiles will all increase impoundment habitat quality (Burger 1973). By diversifying the area of open water with marshland, ditches with high spoilbanks, and plantings for food and cover, the wetland can be made beneficial to waterfowl, furbearers, wading birds, marsh birds, and warmwater fish (Yoakum et al. 1980).

FISH AND WILDLIFE MANAGEMENT RECOMMENDATIONS FOR NATURAL AND ALTERED POCOSINS AND RELATED FRESHWATER WETLANDS

General Recommendations

Large farms. Planning is the key to developing large farms from pocosins both for the sake of wildlife (Figures 44a, 44b, and 44c) and economic success. The most important planning documents are accurate and detailed soils maps. Even though the organic soil surface is flat, the mineral subsoil has undulations caused by relict dunes and old stream channels resulting in deep organic deposits that are often in close proximity to shallow organic or mineral soils. Since deep organic soils are agriculturally unproductive without intensive management, knowledge of their location can substantially reduce clearing costs. If peat mining is not

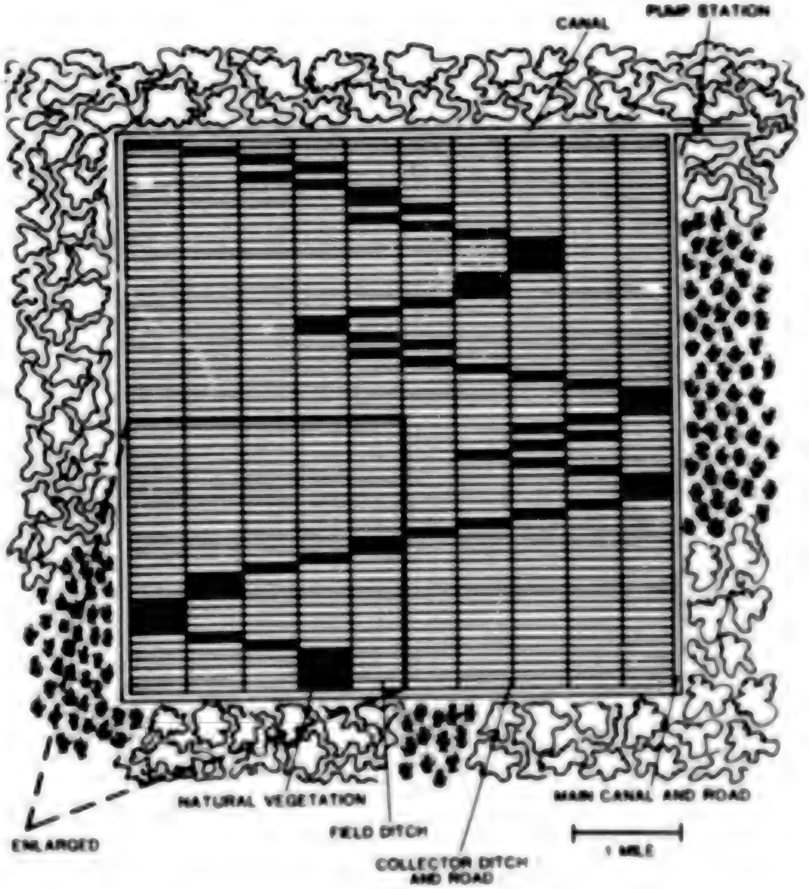

Figure 44a. Hypothetical plan for a large farm in pocosin regions. Smallest rectangles represent field units separated by ditches and canals. Dark rectangles represent areas of deep organic soil where natural vegetation may be left.

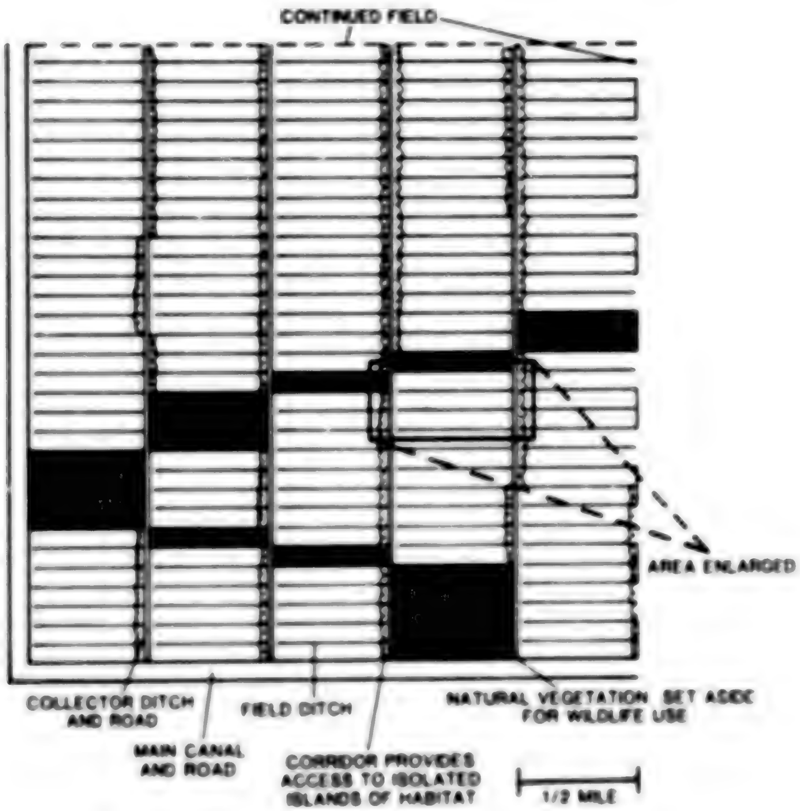
CONTINUED FIELD
AREA ENLARGED
COLLECTOR DITCH AND ROAD
FIELD DITCH
NATURAL VEGETATION SET ASIDE FOR WILDLIFE USE
MAIN CANAL AND ROAD
CORRIDOR PROVIDES ACCESS TO ISOLATED ISLANDS OF HABITAT
1/2 MILE

Figure 44b. Enlarged portion of Figure 44a.

contemplated, these deep organic areas are best left in natural vegetation to serve as corridors or islands for wildlife. If farm clearing proceeds without planning, these agriculturally unsuitable areas will be discovered after the original vegetation has been removed, in which case they may be left to regenerate naturally or be maintained at early stages of succession by periodic mowing or burning.

Large farms have extensive road networks associated with drainage systems; and with proper planning many could be eliminated without removing access to fields. Abandoned roads can be allowed to regenerate in natural vegetation and serve as corridors that connect habitat islands. Even roads that remain in use can have vegetated roadsides and occasional trees.

During clearing, some windrows should be left or only partly burned. These will provide wildlife residence and food if seeded or allowed to grow up in natural vegetation.

Impoundments can be incorporated at many points in the drainage system to help purify water and provide useful wildlife habitat.

If large farms are managed to consider wildlife on a continuing basis, there are many options. Edges of corridors, ditches, and fields can be planted in wildlife foods; or natural vegetation can be encouraged to provide food and cover. Native trees can be planted along canals, ditches, and corridors to create cover and provide windbreaks against soil erosion. Canals and ditches can be shaped with gentle slopes to minimize soil loss and maximize wildlife use. Housing structures may be constructed, or natural structures may be left for wildlife at any field edge or habitat interface. Agricultural crops may be left for wildlife at field edges or in corner blocks.

The character of most large farms (many repetitions of similar small field units bordered by drainge ditches) provides much potential for wildlife use. Planning large farms for wildlife is essential since these represent major losses of natural wildlife habitat. All options may not be possible for all farms, but with careful planning most can be employed at minimal cost to the farmer.

Small farms. Small farms that occupy pocosins or related freshwater wetlands tend to be in areas of best natural drainage and often have irregular shapes conforming to the natural landscape and watercourses (Figure 45). They are often drained by irregular patterns of ditches which may or may not be in conjunction with natural drainage. With a little planning and work, and with minimal expense, these farms can produce a wide variety of wildlife. Natural watercourses should be left unaltered if possible and strips of natural vegetation left along them to serve as cover and wildlife corridors. Drainage ditches may function in similar fashion if natural vegetation is encouraged along at least one side. Ditch edges and sides should be designed to minimize erosion and siltation, and native trees can be planted along them to serve as windbreaks. Impoundments in conjunction with drainage can be created to benefit both farm animals and wildlife. Production of wildlife food in and

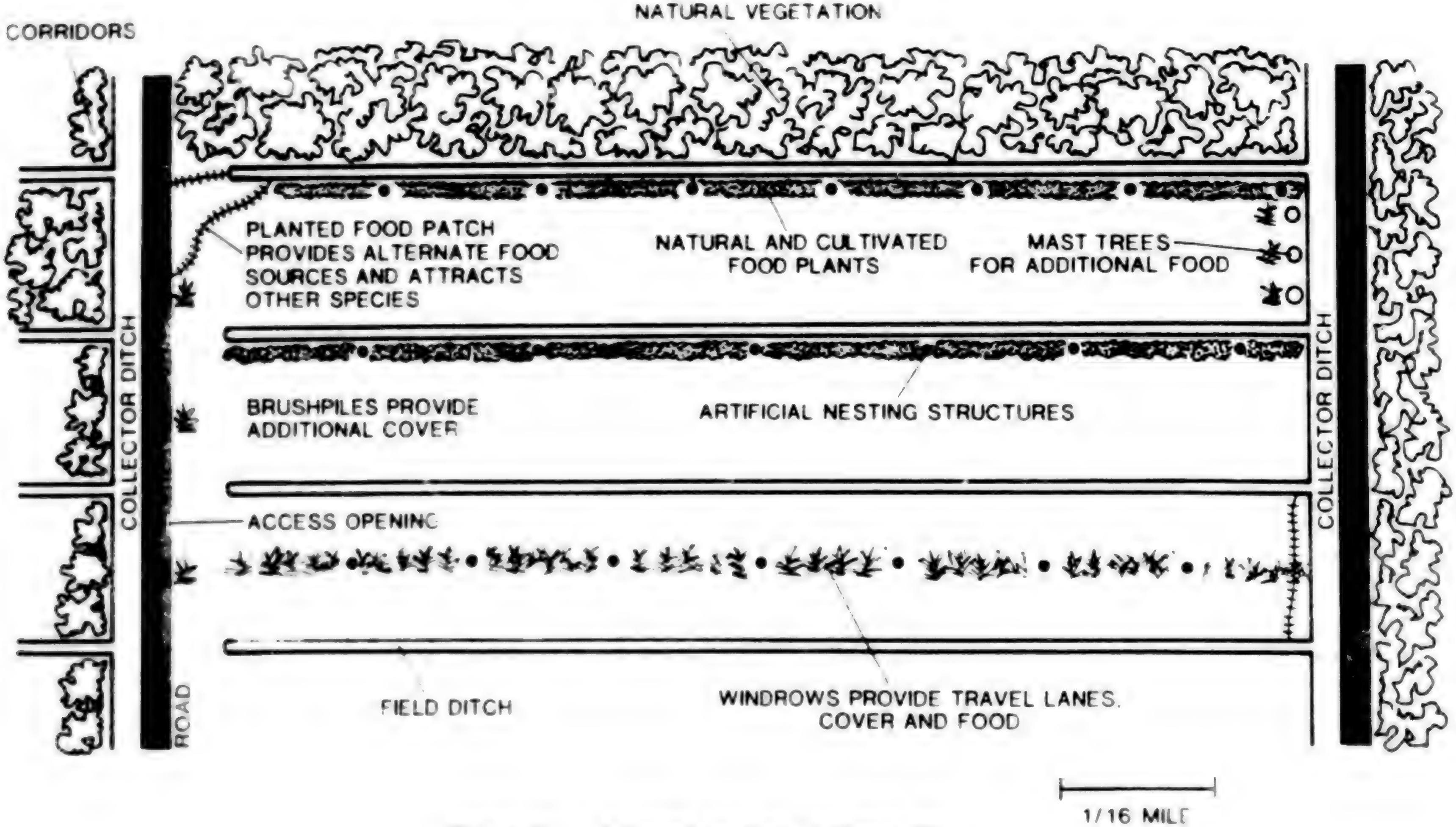
NATURAL VEGETATION
CORRIDORS
PLANTED FOOD PATCH PROVIDES ALTERNATE FOOD SOURCES AND ATTRACTS OTHER SPECIES
NATURAL AND CULTIVATED FOOD PLANTS
MAST TREES FOR ADDITIONAL FOOD
COLLECTOR DITCH
BRUSHPILES PROVIDE ADDITIONAL COVER
ARTIFICIAL NESTING STRUCTURES
COLLECTOR DITCH
ACCESS OPENING
ROAD
FIELD DITCH
WINDROWS PROVIDE TRAVEL LANES, COVER AND FOOD
1/16 MILE

Figure 44c. Enlarged portion of Figure 44b.

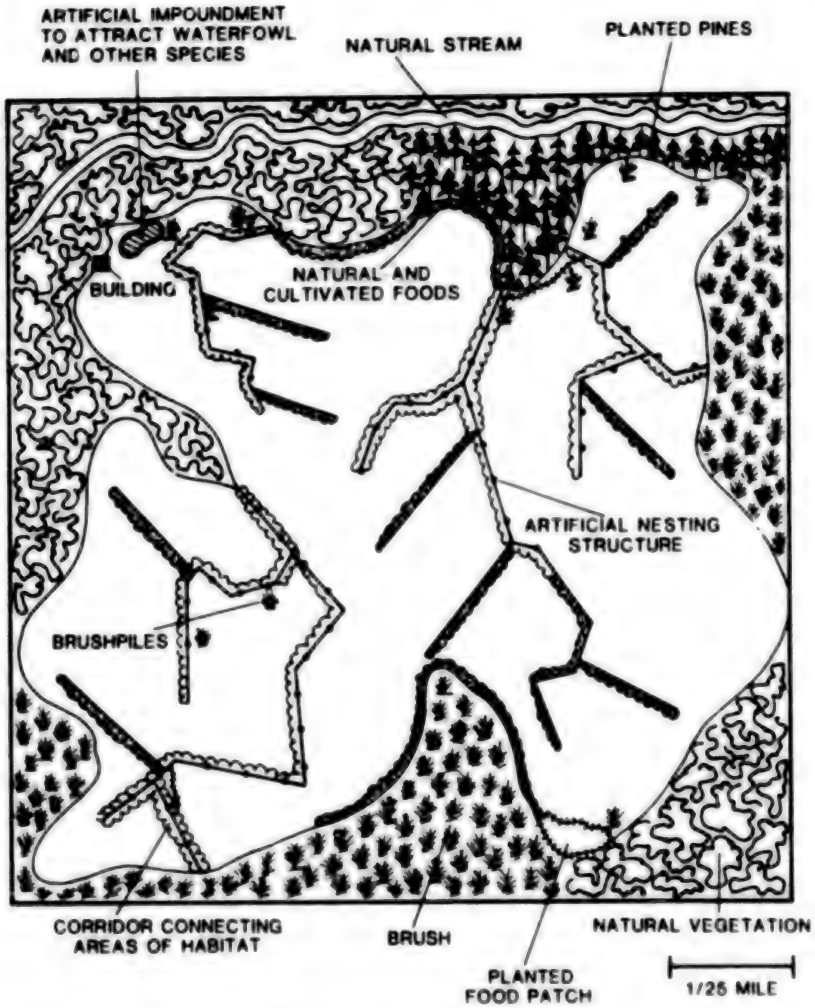
ARTIFICIAL IMPOUNDMENT TO ATTRACT WATERFOWL AND OTHER SPECIES
NATURAL STREAM
PLANTED PINES
BUILDING
NATURAL AND CULTIVATED FOODS
ARTIFICIAL NESTING STRUCTURE
BRUSHPILES
CORRIDOR CONNECTING AREAS OF HABITAT
BRUSH
PLANTED FOOD PATCH
NATURAL VEGETATION
1/25 MILE

Figure 45. Hypothetical plan for a small farm in pocosin regions. Spacing of ditches is irregular and follows natural drainage patterns.

around agricultural fields is compatible with good farming. Crops can be left for wildlife at field margins or in corner blocks. Other wildlife foods can be planted along field and road edges, ditches, wildlife corridors, or natural watercourses; and native plants can be encouraged in these areas by appropriate regimes of mowing and/or burning. Wildlife cover can be provided by enhancing native plant growth at any edge, by using stumps or cut brush to make windrows and brushpiles, or by creating wildlife corridors or windbreaks. Housing for selected species can be constructed and placed along any waterway or habitat edge.

Managed forests. Most managed forests in regions containing pocosin and related freshwater wetlands are monocultures of pine. Several practices are desirable to enhance these areas for wildlife (Figures 46a, 46b, and 46c). Commercial pine forests should be managed in blocks of around 20-100 ha (50-250 ac) for best wildlife use. However, appropriate size of blocks may be dependent on surrounding vegetation with large blocks being desirable when forests are surrounded by cleared land (Harris et al. 1982). Cutting schedules should be planned to place clearcut harvest blocks next to blocks in mid-rotation as this will insure maximum "edge effect" when summed over the rotation of blocks (Harris and Marion 1982). When thinning is necessary, "third row"

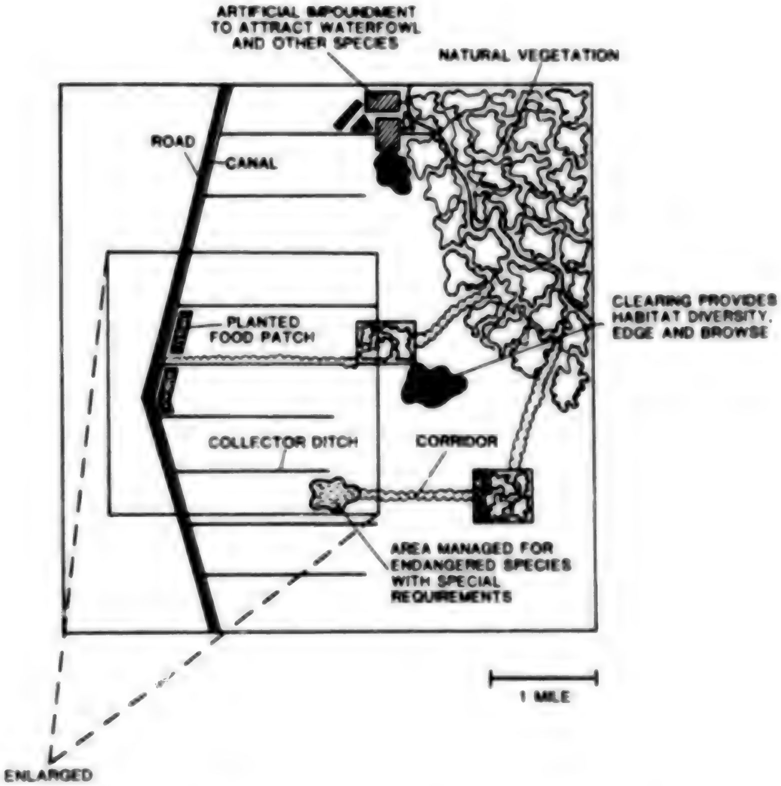
ARTIFICIAL IMPOUNDMENT TO ATTRACT WATERFOWL AND OTHER SPECIES
NATURAL VEGETATION
ROAD
CANAL
PLANTED FOOD PATCH
CLEARING PROVIDES HABITAT DIVERSITY, EDGE AND BROWSE
COLLECTOR DITCH
CORRIDOR
AREA MANAGED FOR ENDANGERED SPECIES WITH SPECIAL REQUIREMENTS
1 MILE
ENLARGED

Figure 46a. Hypothetical plan for a managed forest in pocosin regions.

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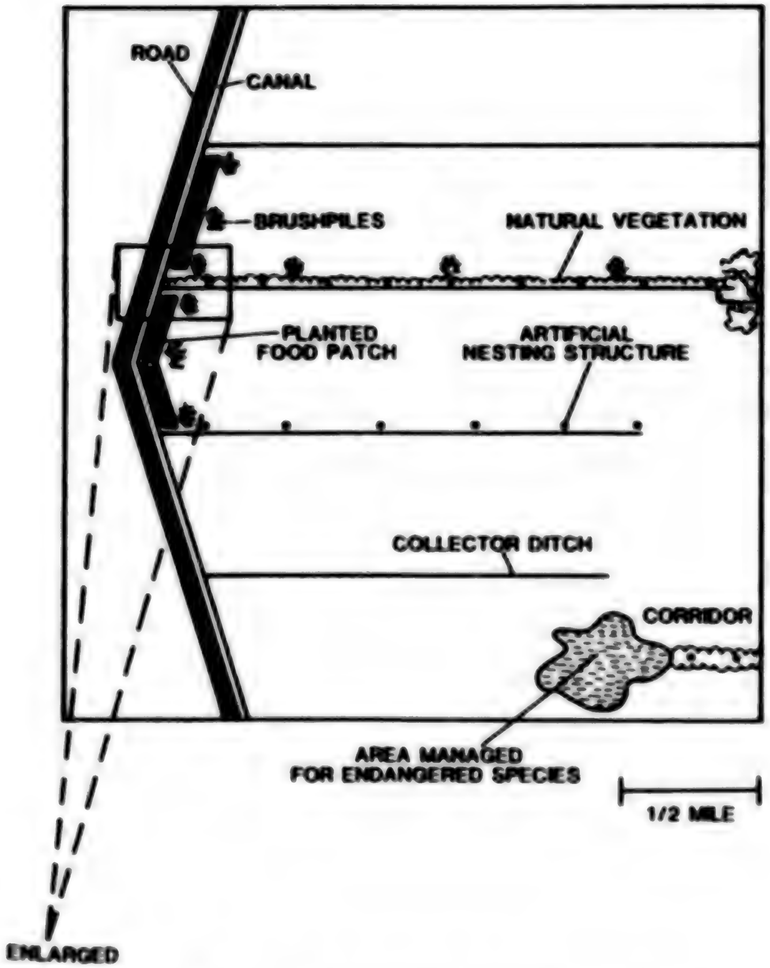

Figure 46b. Enlarged portion of Figure 46a.

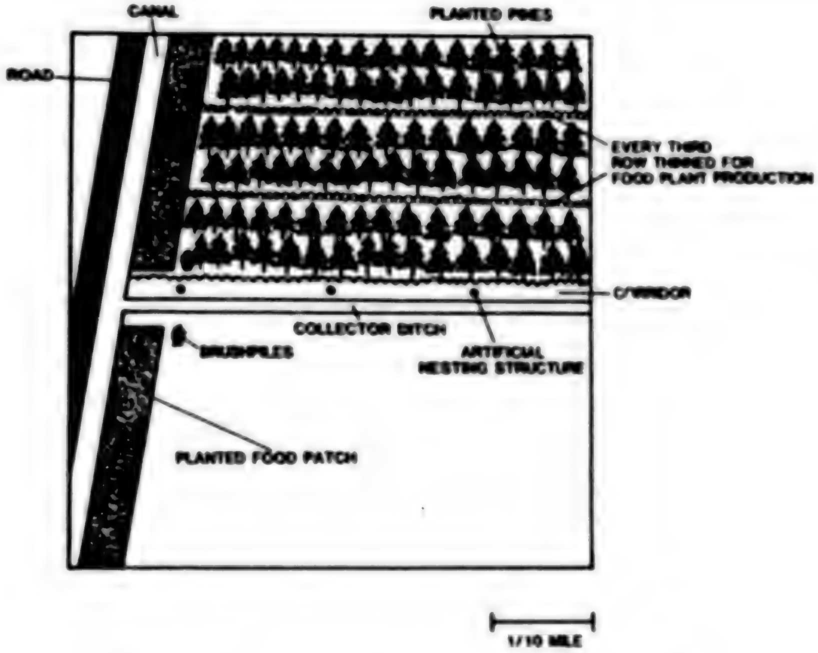

Figure 46c. Enlarged portion of Figure 46b.

thinning is best with wildlife food planted in the thinned rows. Management of understory for hardwoods should be encouraged at all edges and within blocks if possible. This will increase the usually low wildlife food supply of mid-rotation, closed-canopy pine stands. Islands of hardwoods should be preserved if present as they provide nesting cavities as well as mast. If natural vegetation is not sufficient, newly logged areas can be planted with annual foods during early stages of regeneration. Annuals permit control on a yearly basis if excessive competition with young trees is evident. In older stands, controlled burning at three- to five-year intervals can be used to promote understory food production, but more frequent burning or clearing may be detrimental. Impoundments created for fire fighting can serve as useful wildlife habitat and can be managed as outlined in previous sections. Cover can be increased by promoting natural vegetation along any edge, and by leaving windrows and stump-piles in newly-logged or cleared areas. These also provide additional food if seeded or allowed to be overgrown by natural vegetation. Wildlife housing structures may be placed along any edge or watercourse to provide artificial cavities for specific species.

Natural forest-land refuges. A few large tracts of pocosin and related freshwater wetlands have been set aside as natural forest-land refuges. These include Croatan National Forest, Holly Shelter Game Lands, and Angola Bay Game Lands. Such areas benefit all wildlife native to pocosins, but are of particular benefit to rare or endangered species such as black bear. Indeed, these areas seem to provide the only long-term hope for viable bear populations in eastern North Carolina (Tom Monschein, personal communication).

The management cornerstone of any natural forest-land refuge is a large contiguous block of natural habitat that is ideally allowed to respond to natural patterns of weather, hydroperiod, and fire. Large blocks of natural habitat act as refuges for species with specific habitat tolerances as well as for species that need seclusion. Often "non-management" is not feasible or practical, and the level of manipulation should be at the discretion of the manager (Figure 47). For instance, some construction of canals and fire breaks is often desirable, and controlled burns may be substituted for natural ones. If hunting is desired, it will be facilitated by creation of access trails or roads. Clearings varying from 1.2-4.0 ha (3-10 ac) may be placed along roads creating edge for deer, rabbit, and quail. Clearings are created by removing vegetation, burning, and then planting with natural foods or agricultural crops for wildlife use, or by roll-chopping with or without subsequent burning (Figure 48). The latter type of clearing provides natural foods by stimulating shoot and mast production. Brushpiles and/or artificial housing structures in conjunction with openings may also be desirable.

Another common management technique in natural forest-land refuges is the construction of impoundments. These are commonly 81-161 ha (200-400 ac) and once created provide useful habitat for waterfowl, wading birds, furbearers, alligators, and other species. If local water is too acid to produce natural waterfowl food, an impoundment can be limed to raise the pH. Impoundments may be drained in the summer to improve growth of native species or permit planting of wildlife crops and then reflooded in the fall when most migratory waterfowl are present. Edges can be planted to wildlife foods or be allowed to produce natural foods.

Natural forest-land refuges are essential to the concept of good wildlife management on a regional basis. If these areas are not created and maintained in pocosin and related wetland habitat, some species presently protected by pocosins may be lost.

Specific Management Measures

Corridors and habitat islands. As more natural land is developed for human use, wildlife habitat is lost on a regional basis. Some wildlife species adjust well to modified or disturbed habitats (e.g., rabbit, dove, deer) while others do not (e.g., bear, mountain lion, red-cockaded woodpecker). If wildlife diversity is to be maintained, the conversion of large segments of natural habitat to farms or forestry should be mitigated by systems of habitat islands and corridors within developed tracts.

Even through the appropriate size for mitigating islands depends on many factors, there are some ecological principles that can help determine how much land to set aside. First, the appropriate size of islands is inversely proportional to their isolation (Harris et al. 1982). If islands are very isolated, they should be large; if they are contiguous with natural habitat, they may be as much as ten times smaller and still retain the same natural qualities (Harris et al. 1982). Second, each wildlife species uses a characteristic amount of habitat. Since black bears are large and very wide-ranging, their habitat needs can be used to set an upper limit on habitat island size. On the average, a bear requires the resources available in approximately 870 ha to 9,107 ha (2150-22,500 ac) of natural habitat. This may be divided into separate units to sizes as small as 8 ha (20 ac). On large farms the average area bordered by two collector ditches and two field ditches is 8 ha (20 ac), 805 x 100 m (2640 ft x 333 ft) or at the very lower limit of usable size for bear. For wildlife in general, 20 ha (50 ac) is a recommended habitat island size (Tom Monschein, personal communication). Thus, large farms would need to have several sections retained as habitat islands.

Habitat islands should be connected to one another and to adjacent undeveloped land by travel corridors along roads and collector ditches. These can be developed by encouraging native vegetation or by plantings. A good width would be 30 m (100 ft) or greater. With most standard drainage layouts the establishment of corridors along collector ditches will space the corridors at intervals of 800 m (2625 ft). If some other drainage spacing is used, corridors should be left or created at intervals of no less than 1.0 km (3280 ft). Whenever natural streams are included in the drainage network, their floodplains may act as natural corridors.

Cover. When pocosins and other freshwater wetlands are converted to agriculture or silviculture, changes in wildlife use may be due more to alteration of cover than anything else. Large farms leave only a small fraction of the ground cover that was available before clearing and managed forests reduce aerial cover by replacing mature trees and snags with monocultures of young pines. In both instances, one irony is the fact that clearing actually produces new cover in the

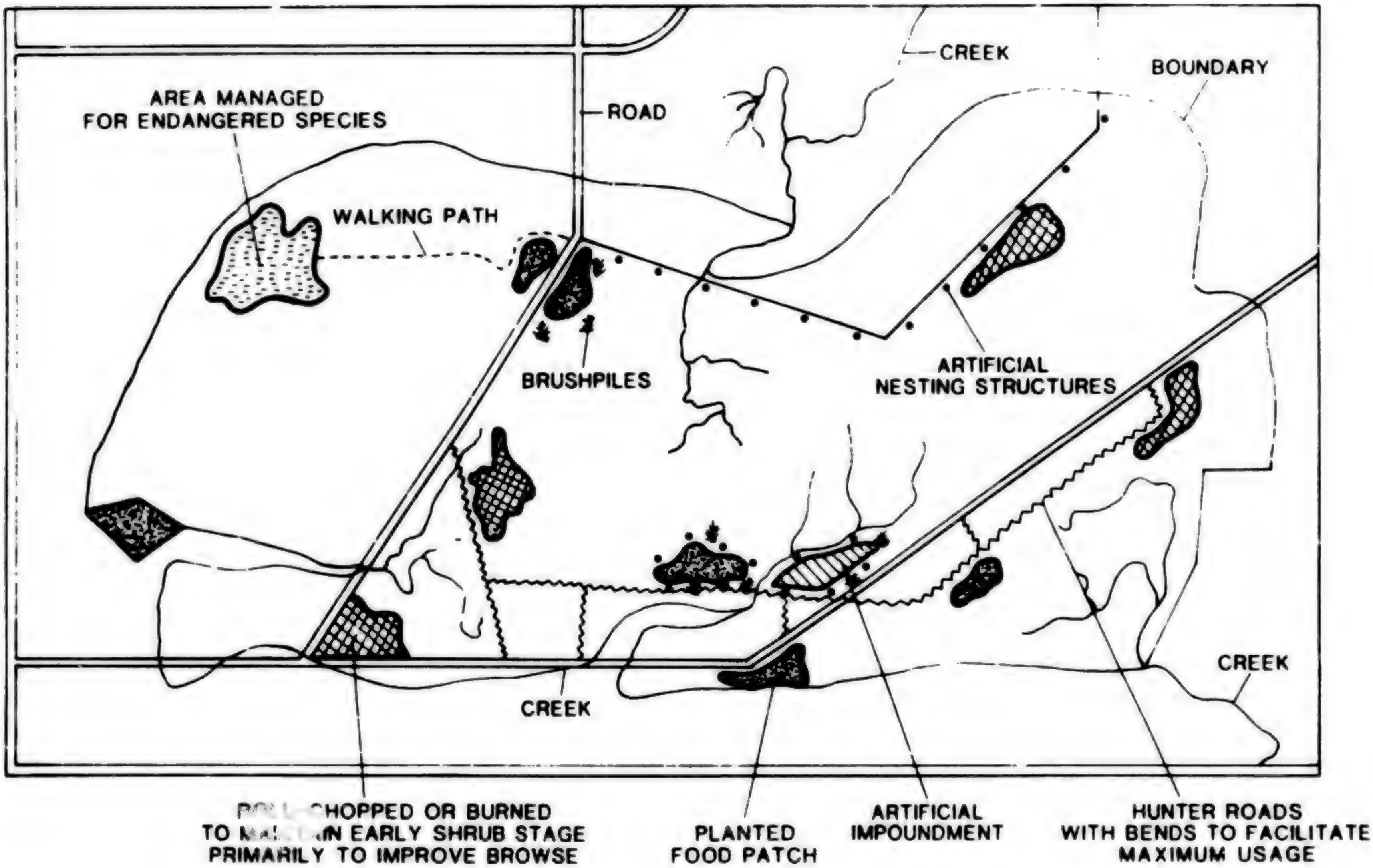

Figure 47. Hypothetical plan for a natural forest-land refuge in pocosin regions.

Figure 48. A clearing in pocosin created by roll-chopping.

form of windrows and stump piles (Figure 39) that are later removed. Rather than clearing completely, it is recommended that some windrows and stump piles be left as wildlife cover. Some could be left in fields while others could be left at the end of roads, along roads, or at borders between developed and undeveloped land. In addition to windrows and stump piles, ground cover can be improved by leaving natural vegetation along fences, ditchbanks, canal banks, roadsides, railroad rights-of-way, waste areas, and odd corners.

For grassland or field nesting species, cover height is important. To be effective it must conceal an animal but allow adequate outward vision. An effective minimum height is 10 to 30 cm (4-12 in) for most small to medium-sized game species. An alternative is increased use of improved bermuda or fescue pasture for livestock. Pastures should have drainage ditches with gently sloped slides (3:1 or greater) to permit mowing. The combination of gentle ditch-slopes, level pasture, and stump piles will provide a variety of cover opportunities. Normal grazing should keep most vegetation at an effective cover height.

One of the most important components of aerial cover is cavity or den trees. Red-cockaded woodpeckers, bears, squirrels, fox, bobcat, wood ducks, raccoons, and other small birds and mammals require den trees or some similar substitute cover. Besides nesting cover, den trees also provide cover for brood-rearing, hibernation, shelter, and seclusion from predators. Any nut-producing trees with the capacity to provide dens or trees with existing cavities or hollow trunks should be marked and saved during timbering and along margins of agricultural fields or peat-mining areas whenever possible.

Windbreaks. Openings as large as 800-1,000 ha (1,980-2,470 ac) often occur when farms are developed from pocosins or other freshwater wetlands. With the fine texture of many blackland soils, these large openings create the potential for serious wind erosion, particularly in spring during the period between planting and crop emergence. To reduce this problem and also provide wildlife habitat, rows of conifers or hardwoods can be planted in conjunction with roads, ditches, windrows, or natural watercourses. When planted in conjunction with roads or ditches, windbreaks should always be located to the south or west in eastern North Carolina. Windbreaks are effective for distances of 10 times their height (U.S. Soil Conservation Service 1978); this relationship can be used as a general guide for spacing. They are most effective for wildlife if developed in conjunction with some other cover such as windrows or stump piles and if they have food plantings or artificial residence structures where appropriate.

Roads. Development of freshwater wetlands for agriculture or forestry involves the creation of extensive road networks. These are built from the leveled and compacted spoil of adjacent canals or ditches (Figure 49) and their construction is often a by-product of drainage improvement rather than a primary objective. Roads require maintenance and interrupt natural habitat so their construction should be avoided whenever possible. When canals are constructed it is most preferable to only slightly level the spoil and let the area completely regenerate in natural vegetation.

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Figure 49. Roads associated with clearing are usually built from canal spoil.

If roads or highways and their associated canals cross natural travel corridors, special crossing points may be needed. This can be done by allowing natural vegetation to encroach very near the roadside and installing culverts that bridge canals (Figure 50). The width of these crossing points should be 30 m (100 ft) or greater.

To help control wind and water erosion as well as provide food for wildlife, any roadside can be planted in crops such as lespedeza or clover. If traffic volume is moderate to low, artificial residence structures may be placed along the road.

Wildlife housing. Many species of wildlife benefit from artificial housing structures if local food supplies are abundant (Figures 40, 41, and 42). Examples are squirrels, rabbits, wood ducks, perching birds, raptors, and woodpeckers. These structures should be designed to be durable, to exclude predators, and to be inexpensive. Directions for construction are available from many sources as well as from regional wildlife personnel. Placement should be close to preferred habitat. For most species

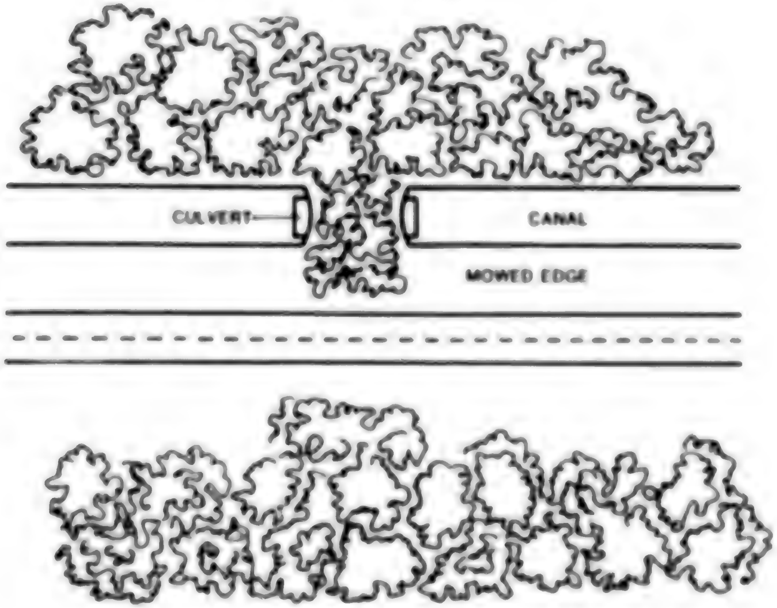

Figure 50. Hypothetical wildlife crossing.

common to agricultural fields or reforestation sites, this will be along clearing edges or in conjunction with ditches, windrows, or stump piles. Artificial housing needs periodic maintenance and cleaning in order to be effective. Yearly inspections are recommended. When structures are manufactured from the by-products of forest clearing for lumber or agriculture, they can be cheap and effective.

Fire. Pocosins usually burn at intervals of less than 30 years, and since most vegetation is adapted to regenerate quickly, managers should let natural fires proceed so long as human life and property are adequately protected. Periodic controlled burning is a useful alternative to total reliance on natural fires, but burning in and around pocosins is a tricky business that must be planned carefully. Burning of pine plantations or savannahs adjacent to natural pocosins should be done in the early spring under favorable conditions of wind, humidity, and water table depth. The water table must be high enough in the pocosin to completely saturate the peat. This allows low ground fires that reach pocosins to burn out. Burning should be at intervals of three to five years, but it may be best to burn every year that conditions are favorable because extended droughts can halt controlled burning for several years in succession. Before shrubby pocosin on peat soil is burned, fire lanes should be established around the plot. Roads and canals may partly serve this purpose, but they may need to be improved or widened. The fire should only be started under favorable conditions of wind, humidity, and water table. One method of starting and controlling the fire is by means of incendiary devices dropped from a helicopter. This starts numerous small fires that burn out when their edges meet (Figure 51). Farmers, foresters, or other managers may find that burning is a useful way to clear around field edges, along ditches or canals, or in windrows. Wherever fire is used, it tends to enhance wildlife food production by promoting the growth of tender twigs and mast, and keeping food accessible to ground animals.

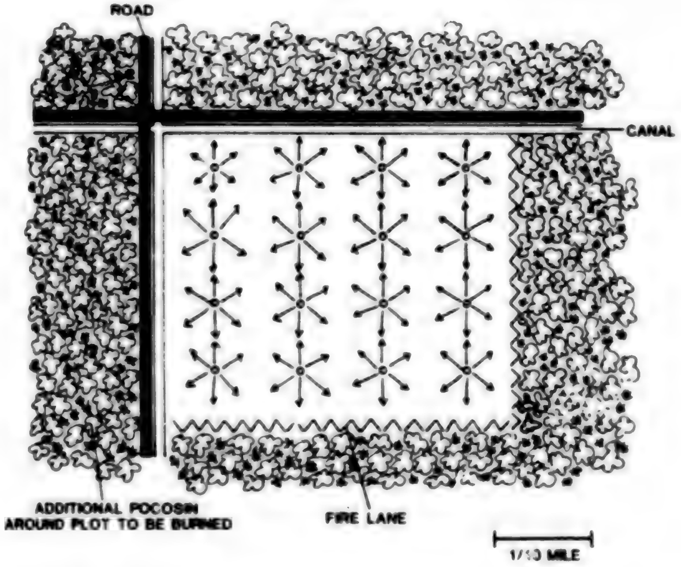

Figure 51. A system for ignition of controlled burns. Many small fires radiate from ignition points.

Roll-chopping. Managers of unmodified pocosins, managed forests, or other areas that contain dense thickets of tall shrubs, or excessively dense stands of young trees, may wish to reduce the vegetation by roll-chopping. A roll-chopper is a large iron drum with protruding blades (Figure 52). The drum can be filled with water or oil for added weight, but in pocosins this is usually not necessary. When pulled by tracked vehicles, roll-choppers do an excellent job of reducing vegetation (Figures 52 and 53). This will stimulate production of new shoots and mast and has been shown to be very effective for deer management. Since reduction of vegetation makes fire more manageable, roll-chopping can be used in conjunction with controlled burns. However, in areas where control of fire is impossible, roll-chopping may be the only practical method for rejuvenating plant growth. If the soil is peaty, roll-chopping should be done only during dry conditions to prevent miring of equipment.

Clearings. In proper situations, clearings are very beneficial to wildlife (Figure 54). In forests, clearings produced by clearcutting will increase edge, create openings, and stimulate growth of additional food plants. In order to maximize edge and maintain age class diversity of timber plots, clear-cuts should be odd-shaped blocks of 20-100 ha (50-250 ac). If clearings are intended specifically for wildlife, smaller blocks of 1 to 8 ha (2-20 ac) may be appropriate. Any mast or den trees should be left whenever possible. Prescribed burning at three to five year intervals will keep clearings open, reduce wildfire hazard, and improve yield and quality of herbage benefiting deer, bear, quail,

Figure 52. A roll-chopper.

Figure 53. A three-year-old clearing created by roll-chopping. Natural vegetation can be seen on right for comparison.

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and others. This will also help keep foods accessible to wildlife. Burning during summer should be avoided because this may eliminate preferred fruit and forage species and destroy nests. If burning is not possible, clearings should be kept open by mowing.

Any of the favorable practices used at field margins are also appropriate for clearings. These include leaving stump piles or other cover, providing artificial housing when needed, leaving travel lanes or corridors in large clearings, and planting either annual or perennial food crops.

Natural and planted foods. Appendices G and H list beneficial native and exotic food plants that can be planted along roadsides, in fields, in forestry clearcuts, or in other clearings. Crops such as corn, soybeans, rye, and wheat can be left for wildlife as well. A good practice, which is supported by the fact that most crop depredation occurs at edges (Monschein 1981), is to simply leave edge strips or odd field corners. For that matter, tolerance of some depredation can be viewed as a good wildlife management practice.

In managed forests and on farms, natural vegetation can be encouraged to regenerate and produce food (young shoots, foliage, mast) by cutting and/or burning. This sort of habitat modification has been very successful for deer in natural pocosin (Tom Monschein, personal communication). Alternatively, native food plants such as lespedeza and clover can be planted in regenerating timber plots, fields, clearing edges, impoundment edges, and roads. If foresters use third-row thinning, the vacant row can be planted. In North Carolina, annual and perennial seed mixtures prepared by the North Carolina Wildlife Resources Commission are available free to private landowners at their request. Generally speaking, any edge or idle space can be successfully used to produce wildlife food.

Wildlife impoundments. In a previous section, impoundments were discussed primarily for their ability to improve the quality of water from agricultural runoff. Even though impoundments for water management will provide wildlife habitat, in some situations it may be desirable to construct impoundments specifically for wildlife.

Impoundments for wildlife have been constructed in pocosin at Croatan National Forest and Holly Shelter Wildlife Management Area. The impoundment in the Croatan is about 160 ha (400 ac) while the one at Holly Shelter is half

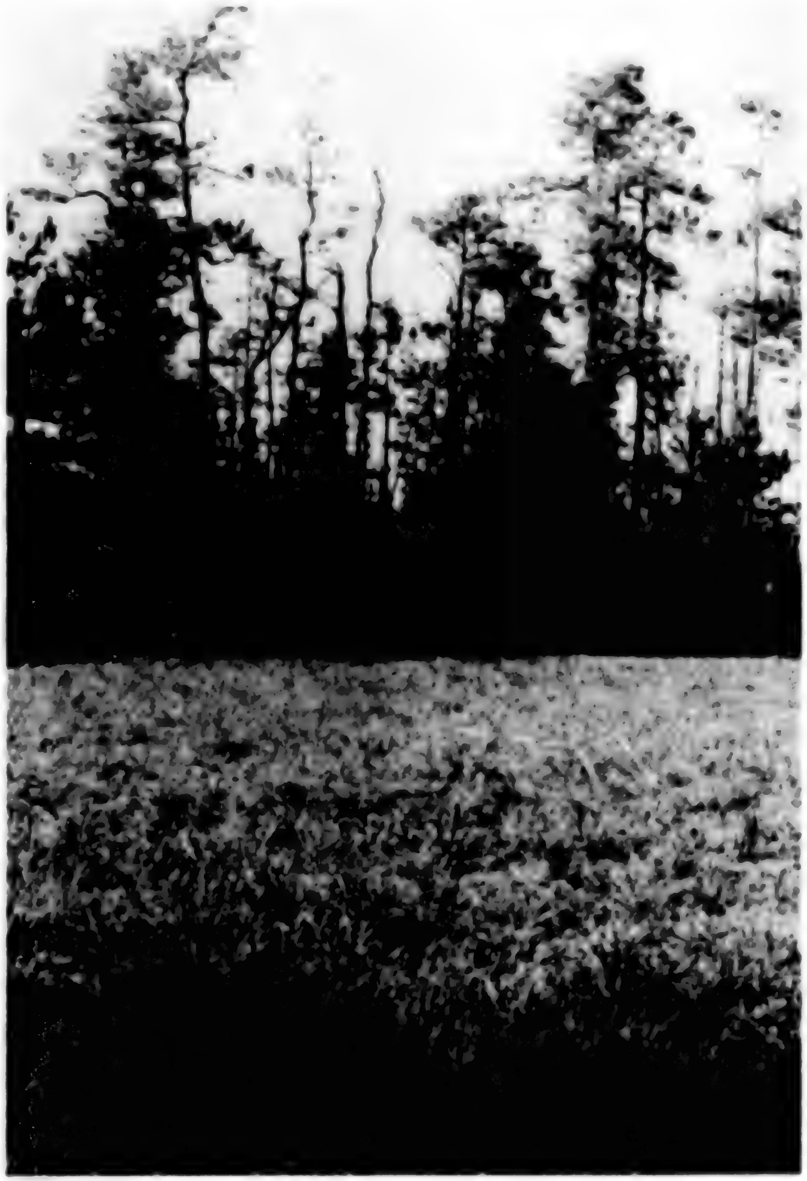

Figure 54. A wildlife clearing planted in red fescue (*Festuca rubra*).

that size. Both are located on cropland that regenerated in shrubs after being abandoned and both were burned and flooded to kill shrubs. They currently have open water with shrubs remaining only at high spots along old ditches and canals (Figure 55). Both impoundments are on organic soils so the water is very acid preventing the growth of most species of favorable aquatic food plants. In an attempt to remedy this, agricultural lime has been added to the Croatan impoundment. If heavy or frequent applications are required, liming probably will not be economically practical. To supplement food within an impoundment, adjacent land can be used for wildlife plantings. This is done at Pungo and Mattamuskeet National Wildlife Refuges, planted mostly to corn and milo on refuge cropland. The work is done by sharecrop agreements with local farmers who raise the crops and then leave designated portions for wildlife at harvest time.

Grading is a problem for large impoundments. Land does not have to be perfectly level to be drained, but must be level for proper flooding. In the Croatan the change in elevation is sufficient that when one end of the impoundment is flooded, the other remains dry. This has been remedied by addition of a central dike which divides the 160 ha (400 ac) impoundment approximately in half. Smaller impoundments have fewer grading problems. For this reason it may be best to have several small impoundments instead of a single large one. Multiple impoundments also increase management flexibility. Some can be filled while others are drained to aerate the soil or permit the cultivation of wildlife crops.

Once constructed, impoundments such as those at Mattamuskeet National Wildlife Refuge (Figure 56) can be managed for submergents or emergents. Submergents require fairly stable water levels during the growing season. In freshwater areas, sago pondweed (Potamogeton pectinatus) and muskgrass (Chara spp.) are the most likely to invade. Both are good waterfowl food plants. To manage for these species, water levels should be dropped to a depth of 15-30 cm (6-12 in) in early spring. Once plants are established and reach the water surface, the depth should be raised to 35-55 cm (14-22 in). This level should be maintained throughout the growing season, even if it is necessary to pump in more water. When the plants thin out after the growing season, the level should be dropped to a depth of 15-30 cm (6-12 in) by January 1. The cycle is then repeated in early spring. After three to five years, a summer drawdown will be necessary to increase productivity. This should begin around February 1 and continue until all water is removed.

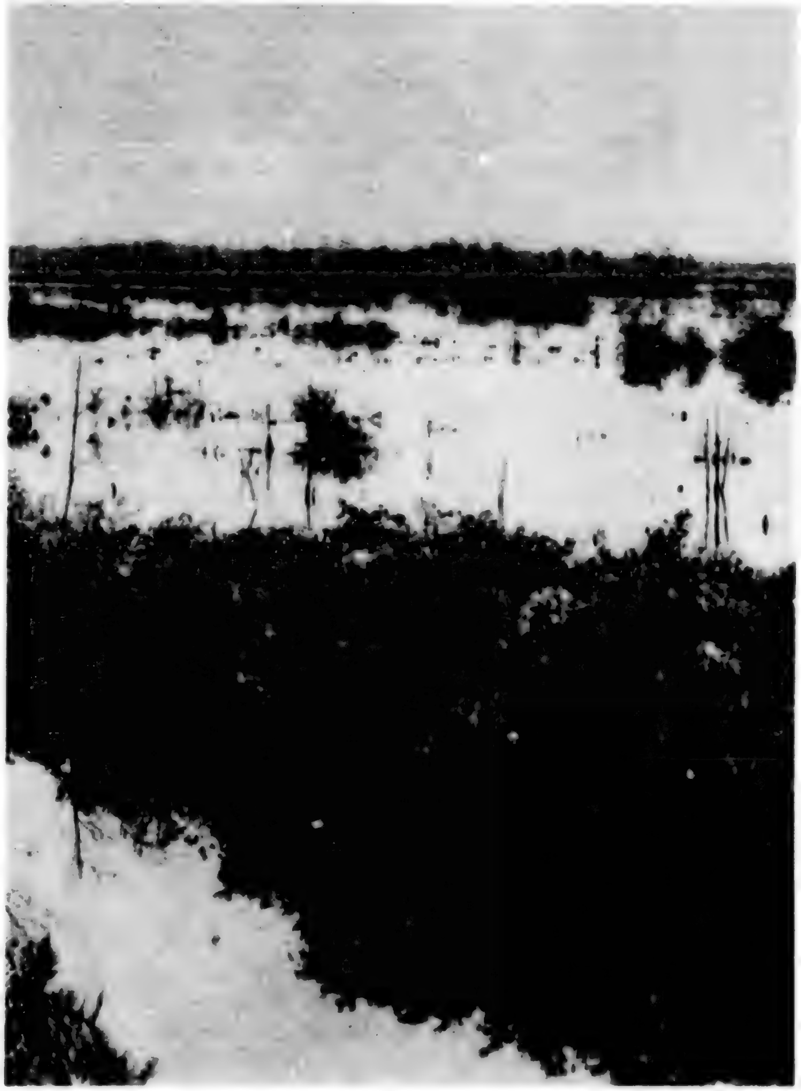

Figure 55. A waterfowl impoundment created from pocosin, Croatan National Forest, Jones County, North Carolina.

To manage for emergents, periodic drainage is necessary. The most common plants to invade will be threesquare (Scirpus spp.), squarestem spikerush (Eleocharis quadrangulata), dwarf spikerush (Eleocharis parvula), and/or millet (Echinochloa spp.). In April or May through July, the water should be

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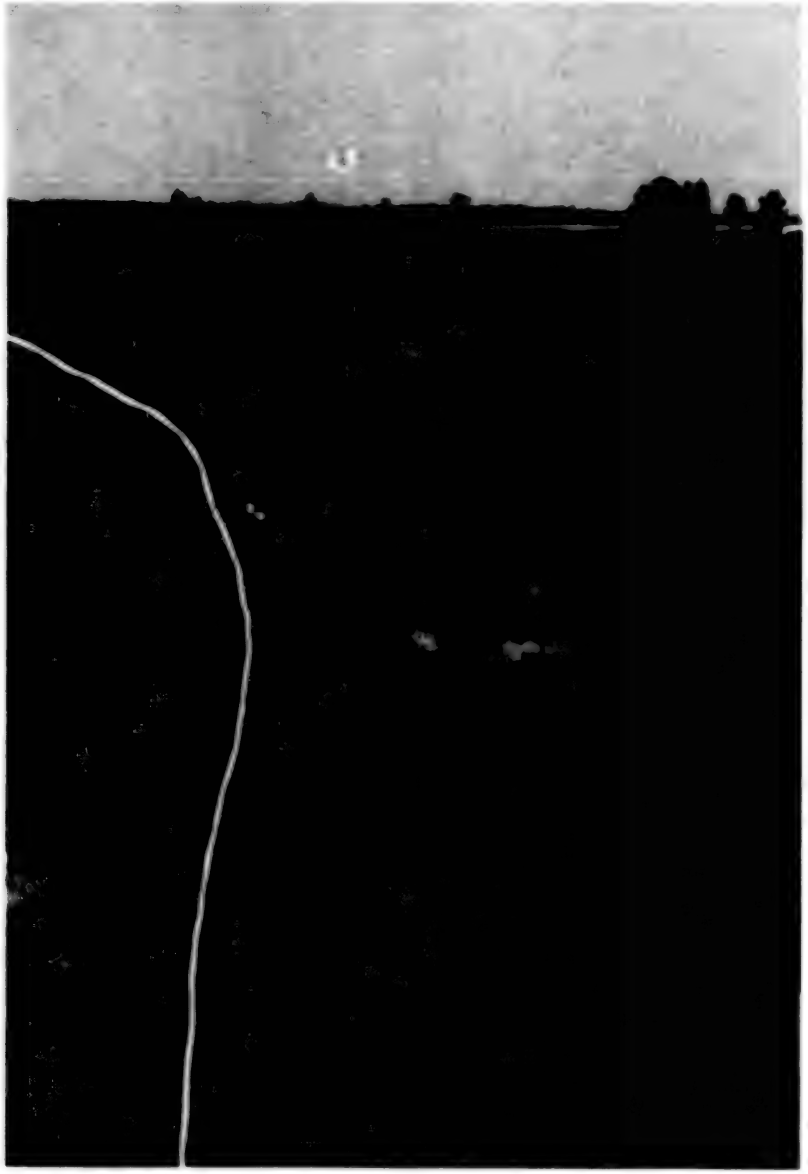

Figure 56. Drained waterfowl impoundments, Mattamuskeet National Wildlife Refuge, Hyde County, North Carolina.

drawn down with the soil surface remaining reasonably wet. Following plant establishment, the impoundment should be periodically flooded with several centimeters (1-2 in) of water that is then slowly removed. By late November, it should be flooded with 20-30 cm (8-12 in) of water. Every four or five years some type of mechanical control will be necessary to eliminate unwanted species and improve productivity. In February or March the impoundment should be drained and the pest species plowed with a large "muck" plow followed by several diskings with large "cutting" plows. It may then be planted in millet and flooded or be allowed to revegetate naturally to desirable species.

Burning is another practice used on the Mattamuskeet impoundments to improve food production, availability, and utilization; control pest species; and encourage desirable ones. It should be done as often as a satisfactory burn can be accomplished. For most impoundments, every five years is acceptable. They should be coordinated with the North Carolina Forest Service and burned between October and February (Hagan 1980). Raising water levels is another option to reduce pest species such as wiregrass (Aristida stricta).

For plantings, wild celery is attractive to canvasback and scaup. Japanese millet or milo and sometimes buckwheat are used. These species require planting and fertilization in August and then flooding in October (Ray Whittenmore, U.S. Fish and Wildlife Service, Mattamuskeet National Wildlife Refuge, personal communication).

Both food and cover should be provided adjacent to the impoundment or be accessible through corridors. Food and cover can be planted or established on banks and earthen dikes in the same ways as on ditch-banks, on agricultural lands, and on forest lands. Browntop millet, Japanese millet and native species are plantings used on the Coastal Plain.

Nesting islands, artificial nest structures, and brushpiles will all increase the impoundment habitat quality. By mixing areas of open water with marshland, ditches with high spoilbanks, and plantings for food and cover, the wetland can be beneficial to a variety of wildlife.

Ditches and watercourses. Forestry operations or farms which occupy converted freshwater wetlands must be artificially drained in most instances. When large acreages are drained, a fairly standard ditch spacing is used. Collector ditches (3.0-4.5 m, 10-15 ft deep) are spaced at intervals of approximately 1.6 km (1 mi) with field ditches (1.8-2.4 m deep) branching off at intervals of approximately 100 m (333 ft). Smaller acreages may be ditched randomly or in association with natural drainage. Owners of previously ditched lands or developers of large farms may not have much control over ditch spacing, but raw ditch edges (Figure 57) should be stabilized with planted grasses or allowed to grow up in natural vegetation (Figure 58). If these edges are properly managed by cutting and/or fire, they will provide wildlife food and cover. Also, they may serve as natural corridors for wildlife if the vegetative strip is at least 30 m (100 ft) wide. If trees are allowed to grow, ditch edges may also function as windbreaks. Trees for windbreaks should be planted on the south and west sides of ditches. Sediment traps may be placed in ditches to improve quality of water released from developed lands. This should enhance wildlife in receiving wetlands and aquatic systems. Where possible, curves should be left in ditches to facilitate siltation and enhance water quality.

If natural water courses are part of an area's drainage, efforts should be made to leave habitat in a natural state. A minimum of channel alterations and improvement should be employed.

Field edges. Field edges along converted wetlands may be associated with agriculture, peat mines, or early stages of forest regeneration. In general, management is identical in all three areas except that the additional option of leaving crops is available in agricultural areas. Natural vegetation such as gallberries and sumac may be allowed to grow with periodic cutting (three to five years) to produce natural mast. In areas being used for pine monoculture, care should be taken at field edges to allow adequate growth of deciduous plants that are principal sources of wildlife food.

Cover for loafing or general use can be created at field edges in several ways. One excellent method on forestry plots and newly-clearly fields is to pile logging slash at field edges in the form of brush piles or windrows. These structures provide some cover immediately, and as they become vegetated they provide more natural cover. Old windrows and brush piles will become completely vegetated if enough soil is incorporated in the pile. Natural cover at field edges can be encouraged by proper regimes of cutting, burning, and planting in strips along field edges.

Field edges are excellent spots for provision of wildlife housing. Windrows and stump piles may provide

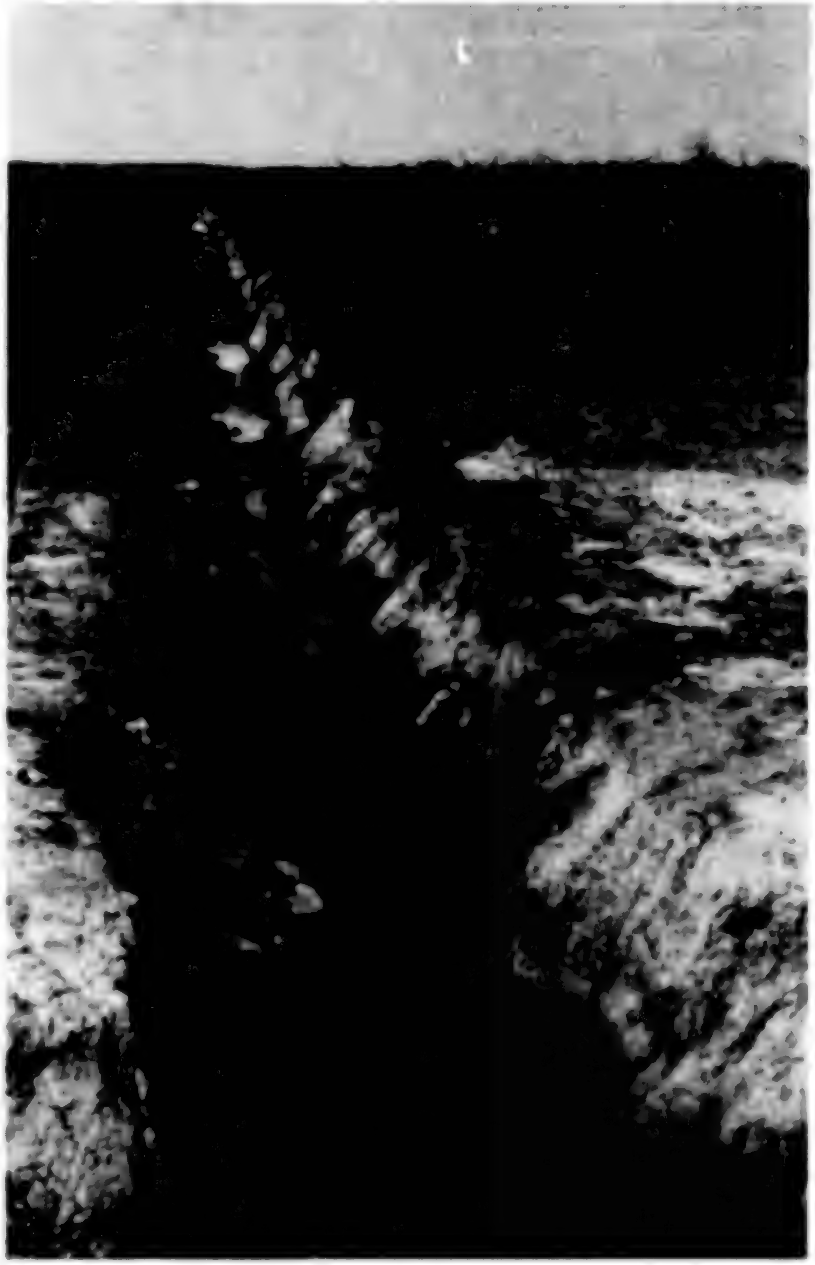

Figure 57. An unvegetated field ditch.

Figure 58. A vegetated field ditch.

housing for many animals and artificial residences such as nest boxes can also be constructed.

Brushpiles and windrows. Brushpiles or windrows of dead vegetation are effective for wildlife enhancement, particularly in areas being cleared. Trees being removed are an excellent wildlife resource that will be wasted if burned. Although different sizes of brushpiles or windrows may be optimal for various species, in practice, sizes are determined by field clearing methods. For example, agricultural windrows may be as much as 2.5-9.0 m (8-30 ft) wide and 0.8-1.6 km (0.5-1.0 miles) long.

MANAGEMENT OF SPECIFIC SPECIES IMPORTANT IN POCOSINS AND RELATED FRESHWATER WETLANDS

Bear

In 1975, black bear (Figure 59) was given "special concern" status in North Carolina (Cooper et al. 1977). A decline in numbers seems to have resulted from man's disturbing influence and destruction of habitat (Hamilton 1978). In the southeastern Coastal Plain, bear occur primarily in forested wetlands. Due to the increasing conversion of forested wetland habitat to farmland, and the associated construction of roads and canals, bear have been forced to increase their dependence on remaining forested wetlands. Major wetland forest types such as pocosin must be protected to maintain the Coastal Plain bear population (Hamilton 1978, Hamilton and Marchinton 1977).

The black bear's major habitat need is large tracts of undisturbed habitat. Generally, each bear requires about 870-9,107 ha (2,150-22,500 ac) of natural range (Hamilton 1978), and about 20,235 ha (50,000 ac) are needed to support a huntable population (U.S. Forest Service 1971, Barick and Critcher 1975). In order to preserve bear, large tracts of forest land within the state must be set aside and should have controlled access and hunting.

Bears are omnivourous with mast and fruit the bulk of the diet. Oaks and black gum provide major foods, with other plants such as gallberries, huckleberry, pokeberry, and blackberry supplementing when they are in season. Grubs, insects, and corn are minor portions of the bear's diet (Barick and Critcher 1975). Bears will also eat mice, lizards, frogs, snakes, and fish.

Figure 59. Black bear (courtesy of North Carolina Wildlife Resources Commission).

Timber management practice largely determines food quality and supply on managed lands (U.S. Forest Service 1971). Favorable practices for bear on large tracts include site preparation, thinnings, and wide spacing of planted pine to encourage fruit and mast production by stimulating understory plant growth. Seeding for understory food plants where they are not readily available is good practice. Prescribed burning every three to five years is effective in producing mast.

Bear also require dens for hibernation. A variety of sites are used including open areas, depressions in thickets, areas below coniferous trees, and hollow trees. Bear would probably prefer tree dens because of the added protection from weather, high water, man, and hunting dogs. Therefore, large den trees should be left when clearcutting (Hamilton and Marchinton 1977). In the Coastal Plain, bears often den in dense thickets; thus pocosins are good denning habitat.

Other recommendations include closing off areas where bears could be a problem; for example, where bee stands are located, beekeepers should protect them with platforms or electric fences. Key habitat preserves and corridors between preserves must be maintained (U.S. Forest Service 1971). Hamilton (1978) further suggests a delay in the opening of hunting season to reduce the harvest of adult females, and better public relations to create a positive public attitude toward bears.

Deer

The white-tailed deer (Figure 60) is the most important game species in the United States (Trippensee 1948). Barick and Critcher (1975) estimate about a half million deer exist in North Carolina with the majority in the eastern counties. Herds are continuing to spread, and they should double by 1990 to 1995. Deer make good use of edge and are most abundant in managed or agricultural areas interspersed with woodland (Barick and Critcher 1975). Deer are found almost anywhere there is a minimum of food, water, and cover. In the Coastal Plain, hardwood bottomlands and extensive swamps furnish excellent cover (U.S. Forest Service 1971).

Deer have a home range of about 60-120 ha (150-300 ac) (U.S. Forest Service 1971, McAbee 1979). The ideal range has about 50% second-growth successional forest, and about 25% each of mature woodland and non-forested land. Natural refuge areas for deer should be about 80-160 ha (200-400 ac) (Trippensee 1948), broken into management blocks. The U.S. Forest Service (1971) suggests minimum block sizes of 16-48

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Figure 60. White-tailed deer (courtesy of R. Smith, USFWS).

ha (40-120 ac) in pine forests, 12-24 ha (30-60 ac) in upland woodlands, and 4-16 ha (10-40 ac) in gum-cypress bottomland hardwoods. Pine-woods blocks with sandy soil should be 65-81 ha (160-200 ac) with a 40-year rotation (U.S. Forest Service 1971). Corridors for deer movement between habitat blocks are necessary and may be either planted trees or clearcut aisles with stumps or brush (Trippensee 1948).

Clearcutting is very important in deer management. Linear, irregularly shaped cuts are best. Regeneration or intermediate cuts are needed every 8-10 years. The peak production of forage plants will be in the first two to three years and will then decline for the following five to six years. Clearcuts should be small (Barick and Critcher 1975).

Once openings are created, brushy feeding areas can be controlled by mowing, chopping, chaining, cabling, burning, or other methods to speed regrowth (Burger 1973). Planting can also be used. Farm production of corn, soybeans, small grains and pasture are favorable when adjacent to forest cover (Barick and Critcher 1975). In addition, if openings are properly placed, damage to crops will be reduced (Trippensee 1948). The most important deer food items on the Coastal Plain include titi, hollies, red maple, blackberry, oak, sumac, mushrooms, lespedeza, pokeweed, greenbriar, switch cane, black cherry, jessamine, red chokeberry, hawthorn, honeysuckle, corn, and soybeans (U.S. Forest Service 1971, Sossaman and Weber 1974). Native species should be encouraged in openings and as understory where possible. In open areas where native species are not present, adapted species (Appendix H) should be planted. Plantings should be approximately 0.4-0.8 ha (1-2 ac) in size and well interspersed.

For cover, clumps and strips of shrubs and trees near water are best (Burger 1973). In wetlands, hammocks and high ground above flood level should be maintained for bedding and food (U.S. Forest Service 1971).

Other management options for deer are: 1) seeding unused roads and trails to forage crops, 2) providing access for hunters to harvest as much as 25-30% of the herd annually (Burger 1973), and 3) release of thickets and protection of old home sites where cover is needed (U.S. Forest Service 1971).

Red-Cockaded Woodpecker

Once common in mature pine forests of the southeast, the red-cockaded woodpecker is now an endangered species. Its range is reduced and its population has declined due to loss of habitat (Hooper et al. 1980). Jackson (1971) estimated between 3,000 and 10,000 birds still survive; however, Jackson et al. (undated) feel this estimate is inflated. The U.S. Forest Service (1971) estimates a pupulation of 5,300 in the southern national forests.

Live southern pines, usually longleaf and loblolly, are used for nest cavity trees and pine and pine-hardwood forests are needed for foraging habitat. Much of this habitat has been cleared for agriculture. Therefore, appropriate areas must be preserved and managed for this species to survive (Hooper et al. 1980).

The most critical part of the red-cockaded woodpecker's habitat is cavity trees. In any management plan, these must be considered first. As mentioned, longleaf and loblolly pines are preferred, but slash, shortleaf, and pond pines are also used. Trees with active nests are live and usually infected with red-heart fungus (U.S. Forest Service 1971). The tree must exude resin around the nest hole and a new tree will be found when it no longer does so (U.S. Forest Service 1969). The purpose of the resin is unknown; however, the U.S. Forest Service (1971) hypothesizes it may serve as a defense against predators. The trees are usually over 23 cm (9 in) DBH and no younger than 30-40 years old. Most are 60-80 years old. The best sites are mature, park-like stands with 11 to 18 m^2 basal area/ha (50-80 ft^2/ac) and few or no understory hardwoods above 4.6 m (15 ft) tall. A prospective site should be at least 2-4 ha (5-10 ac) to provide cavity trees in the future (Hooper et al. 1980). On sites 80 ha (200 ac) or more in size, the birds can be managed with much greater confidence (Jackson et al. undated).

A colony will consist of one to many trees with cavities, and a single tree can have one to several cavaties. Each cavity can be used for several years (Jackson et al., undated). The entrance holes are 4-5 cm (1.5-2.0 in) in diameter and usually 12 m (40 ft) or more above ground (U.S. Forest Service 1969). However, they have been found as low as 1.2 m (4 ft). Generally, an entrance hole is below any live limbs (Hooper et al. 1980). Colonies encompass 3-16 ha (7-40 ac) of nesting, roosting, and replacement trees, and feeding area (U.S. Forest Service 1971, Hooper et al. 1980). Development or any other disturbance should be prohibited within 100 m (330 ft) of any nest tree.

The red-cockaded woodpecker's major food is forest insects and other arthropods (85%); however, they also feed on some small fruits and seeds (15%). Major items are ants, beetles, caterpillars, spiders, and seeds of wax myrtle and magnolia (U.S. Forest Service 1971).

The woodpeckers seldom tolerate understory trees more than 4.6 m (15 ft) tall. To maintain understory height, prescribed burning can be used; however, precautions should be taken to protect cavity trees. Grass should be clipped and debris removed within 1 m (3 ft) of the tree base before a fire is set. Burning is used in the Green Swamp Nature Preserve for red-cockaded woodpecker management, and costs and schedules for burning are included in McIver (1981).

Other management suggestions include: 1) thinning stands to 11-18 m^2/ha (50-80 ft^2/ac) total basal area; 2) leaving dead or abandoned trees for other animals so that they will use them instead of the good cavity trees; and 3) treatment of infestations of the southern pine beetle (_Dendroctonus frontalis_) by removing or burning affected trees or by spraying them with approved pesticides. (Hooper et al. 1980).

Furbearers

The important furbearing wildlife species that occur in pocosins and related freshwater wetlands are bobcat (Figure 61), gray fox, raccoon (Figure 62), muskrat, otter, mink, opossum, and to a limited extent, beaver. Management of these species will be discussed as a group and fox and bobcat will be discussed separately.

In natural pocosins and other wetlands, management for furbearers involves three basic factors: 1) the preservation of hardwood stands (if present) for predator and/or prey habitat; 2) water quality management to maintain aquatic prey densities necessary for some species; and 3) the creation of edge (Randy Wilson, North Carolina Wildlife Resources Commission, Burgaw, N. C., personal communication). Edge can be in two forms, aquatic or terrestrial. Aquatic edge can be created in wetlands by digging shallow ditches that have gentle side slopes for decreased siltation and increased

Figure 61. Bobcat (courtesy of North Carolina Wildlife Resources Commission).

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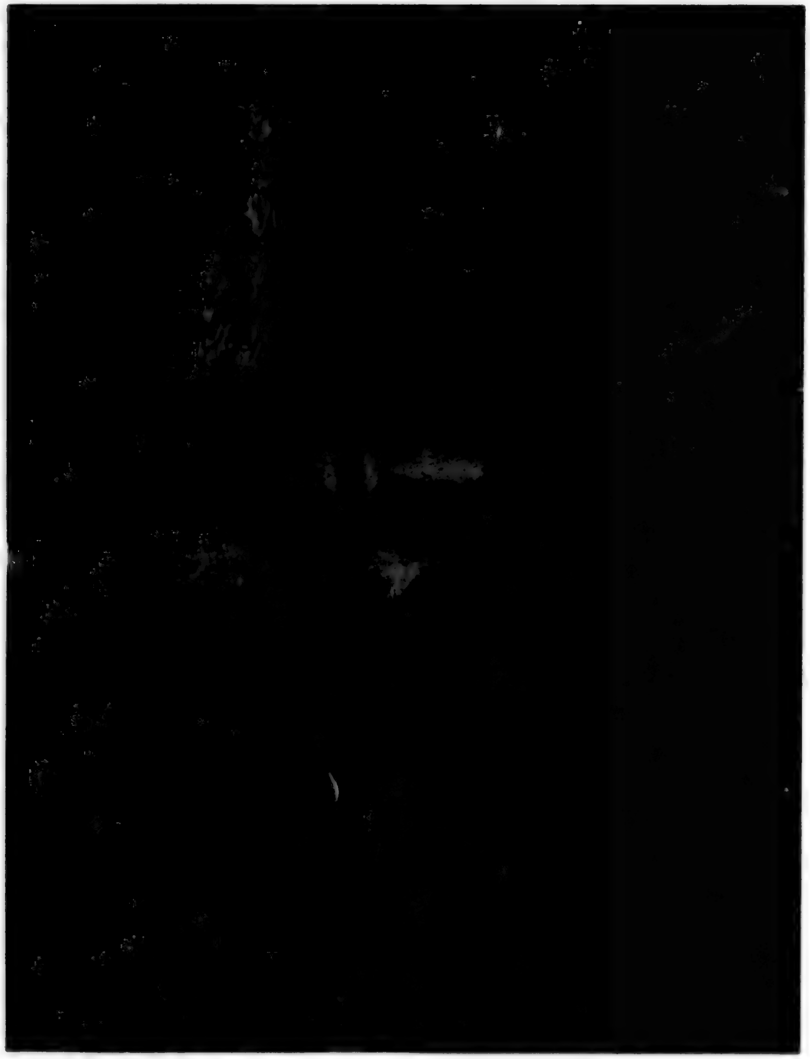

Figure 62. Raccoon (courtesy of North Carolina Wildlife Resources Commission).

crayfish utilization. Raccoon, muskrat, otter, and mink will make immediate use of these ditches if populations of crayfish are initially present. Beaver will utilize ditches if appropriate food plants are available in the vicinity. Terrestrial edge may be enhanced by construction of minimal-use roads or creation of clearings. Clearings can be made by cutting and burning or by roll-chopping. Edge will be productive of ericaceous shrubs important to rabbit, fox, and raccoon. More rabbits will also help fox and bobcat populations. Since unmodified pocosins usually lack both edge and open water, they are generally not very productive of furbearers, with rabbit and bobcat being possible exceptions. Professional opinion is split concerning pocosin use by these species, and published data are lacking.

Most furbearers need natural or only slightly modified habitat in order to fare well. Extensive road and canal construction or extensive clearing and cover modification typical of managed forests can do great harm to furbearer populations. Likewise, the vegetation removal and road and canal construction typical of agricultural conversion can have an even greater impact. These can be minimized by several management practices. Habitat islands and wildlife corridors of natural vegetation in association with roads or canals are very helpful in stimulating furbearer use of farm edges (Randy Wilson, personal communication). These areas provide plant food for furbearers and their herbivorous prey. Hardwoods should be encouraged in habitat islands and cover strips in order to provide mast for furbearers and their prey, as well as for nest cavities. Sizes of islands and corridors are given in other sections. Aquatic furbearers will make use of drainage ditches if they have gentle side slopes and natural vegetation. Mowing or burning should be on a rotation of three to five years. Burning of edges will benefit prey species and thus the carnivorous furbearers such as fox or bobcat.

Gray fox. Gray fox is the common fox of pocosins and related feshwater wetlands. While this species is not thought to penetrate very deeply into unmodified pocosins, it makes good use of edges of pocosins and swamp forests. Moderate building of roads and canals may greatly enhance the use of unmodified pocosin by fox since they will take advantage of increased numbers of small mammals as well as the blackberries and blueberries that are often found in such situations (Randy Wilson, personal communication). In agricultural areas or managed forests, maximum edge should be maintained for the same reasons. Hardwoods of swamp forests or uplands bordering pocosins should be maintained for den cavities. Additionally, stump piles can be left after clearing and vegetation corridors and islands maintained to provide den sites. In general, fox should do well at the edge of any fields or pine plantations that have enough remaining natural habitat to provide escape cover.

Bobcat. The bobcat is the common cat predator of the southeastern Coastal Plain. They are probably most abundant at edges of pocosins, in swamp forests, and upland forests; but they may be found throughout pocosins because of the presence of one prey species, the marsh rabbit. Professional opinion is divided regarding extent of pocosin use by bobcat. Management for bobcats involves enhancement of edge to benefit prey species and preservation or creation of dens. Prey species can be encouraged in unmodified pocosins by the building of some roads and canals to increase edge, in pine stands by appropriate measures to enhance understory browse, and in fields by the improvement of food and cover in edge situations. Denning opportunities are increased by preservation of swamp forest and by leaving old trees or den trees during any farm or forestry clearing operation. In substitution for den trees, stump piles should be left at forest edges.

Quail and Dove

Quail and doves (Figures 63 and 64) require four environmental types: woodland, shrubland, grassland, and cultivated land satisfy their requirements for food and shelter. The size of their populations is directly related to the amount of edge produced by the interspersion of these four types of areas.

Figure 63. Bobwhite quail (courtesy of North Carolina Wildlife Resources Commission).

Figure 64. Mourning dove (courtesy of North Carolina Wildlife Resouces Commission).

There are several ways to provide good cover for quail and doves. Along gullies and ditches, shrubby thickets should be encouraged and planted when necessary. In fields and clearings, stubble should be left to provide winter cover. Shrubby species should be controlled by prescribed burning or mowing every three to five years during periods outside of the summer nesting season. A flushing device can be attached to mowers to help save nesting females. Stump piles or brushpiles for cover will enhance quail populations if they are within 61 m (200 ft) of other escape cover. In addition to stump piles created during clearing, brushpiles can be built with slash from top-pruning of trees in forestry operations. For large clearings of 40 ha (100 ac) or more, one brushpile per hectare (2.5 ac) is sufficient. Top-pruning has the additional benefit of promoting shrubby growth, the preferred loafing cover for both quail and doves. Some slash might also be placed in primary tree forks which creates good nesting cover for doves.

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Marsh Rabbit

Marsh rabbits (Figure 65) are considered most common within wetlands while the cottontail is most common along wetland edges. To encourage marsh rabbits, openings with some shrubs remaining can be created by burning or roll-chopping every three to five years. The shrubs will provide cover and some winter food. In addition, when possible, stubble should be left for winter cover in cultivated fields adjacent to woodlands. Where food is lacking, non-crop wildlife plantings can be used or plots of commercial crops produced. Where needed, shrubby corridors should also be provided along ditches, fences, and through clearings. In addition, brushpiles or stump piles can provide excellent cover in clearings or along field edges where other cover is lacking. For rabbits, brushpiles should be at least 7.6-15.2 m (25-50 ft) long, 1.5 m (5 ft) wide, and 1.2 m (4 ft) high.

American Alligator

The range of the American alligator (Figure 66) is from Albemarle Sound, North Carolina south to Florida and Texas along the Rio Grande and Red Rivers. In 1970, the alligator was assigned endangered status because of rapid decline in populations due to uncontrolled harvest and habitat loss. It is now recovering at a substantial rate and the population is estimated to be about 750,000 in the Southeast (U.S. Forest Service 1971). In Louisiana, controlled alligator hunts are now permitted. However, alligators are still in danger due to continued loss of habitat.

Joanen (1974) reported a North Carolina alligator population of 1,314 animals present in 21 counties. The 21 counties were reported as having 2,626 km^2 (1,014 mi^2) of available alligator habitat. Nine counties had stable populations, four were increasing, and eight were decreasing.

General habitat for alligator includes bottomland swamp, ponds, sloughs, marshes, and slow-moving streams. Prime alligator habitat is found in areas where water turbidity is usually low and water quality high. Alligators are also found where open water occurs with greater frequency than areas covered by emergent aquatic vegetation. Alligators are rarely found in wooded streams due to low sunlight and lack of nesting sites. They prefer fresh to brackish water (salinity < 20 ppt). The nest is built out of decaying

Figure 65. Marsh rabbit (courtesy of North Carolina Wildlife Resouces Commission).

Figure 66. American alligator (courtesy of North Carolina Wildlife Resources Commission).

vegetation and may be 2.4 m (8 ft) in diameter and 0.9 m (3 ft) high. Raccoons are a problem as predators of alligator eggs (U.S. Forest Service 1971).

Young alligators feed on a variety of small animals including snails, crayfish, and shrimp. As they mature, larger vertebrates are included in the diet. Many prey species are most abundant where water quality is high. Marsh grasses and sedges provide nesting and protective cover and serve as habitat for smaller animals young alligators feed on. Alligators use open water for their reproductive activities and holes 4.6-6.0 m (15-20 ft) long adjacent to banks of dikes and levees for escape and hibernation. Home range for females is between 2.4 and 16.2 ha (6-40 ac) while males utilize 20-1416 ha (50-3500 ac) (U.S. Forest Service 1971).

Natural habitat should be left for alligator. Habitat alteration should not be considered within 150 m (500 ft) of permanent open water until holes and nests are located. Holes and nests should be undisturbed if possible. Cutting activities during breeding and nesting periods and conditions that increase water turbidity or choke water with debris should be avoided. In general, activities that alter water levels or quality may be unfavorable and should be avoided.

Waterfowl

Ducks (Figure 67), geese, and swans make limited use of natural pocosin, but some species will make use of modified pocosin. Additionally, waterfowl of the Atlantic Flyway make heavy use of the marshes, lakes, and estuarine shorelines of eastern North Carolina as wintering areas. Five basic management recommendations are suggested: 1) maintenance of high water quality in runoff waters from pocosin and swamp forest, 2) creation of impoundments in pocosin and swamp forest, 3) provision of food by leaving grain and stubble in agricultural fields adjacent to impoundments and natural bodies of water, 4) the use of steel shot by hunters to reduce lead-poisoning of waterfowl, and 5) provision of nest boxes.

Fish of Small Blackwater Streams

Pocosins are unusual freshwater wetlands in that they are not normally associated with dendritic drainage streams, but rather discharge water by sheet flow (Daniel 1981). For this reason, there are few streams associated with the major North Carolina pocosins, and most streams found in pocosins are extremely small (4.5-12 m, 15-40 ft wide). A good example of a pocosin stream is the Southwest Fork of the Alligator River in Tyrrell County. This stream flows through pocosin for over 13 km (8 miles) and seldom exceeds 9 m (30 ft) in width.

Figure 67. Wood duck (courtesy of North Carolina Wildlife Resources Commission).

Since pocosin streams are few, typically blackwater, acidic, and small; they have limited impact on commercial and sport fisheries of the Coastal Plain (Figure 68). Species of importance (>2% of total numbers or weight) in a small blackwater stream in Bertie County, North Carolina, included American eel, bluespotted sunfish, bowfin, flier, golden shiner, ironcolor shiner, eastern mudminnow, mud sunfish, pirate perch, redfin pickerel, swampfish, tadpole madtom, and yellow bullhead (Huish and Pardue 1978). Biomass production in small blackwater streams is usually moderate to low (Wilson Laney, U.S. Fish and Wildlife Service, Raleigh, NC, personal communication).

Management of fish populations in small pocosin streams is contingent on two factors: preservation of the natural stream channels, banks, and floodplains; and preservation of high water quality.

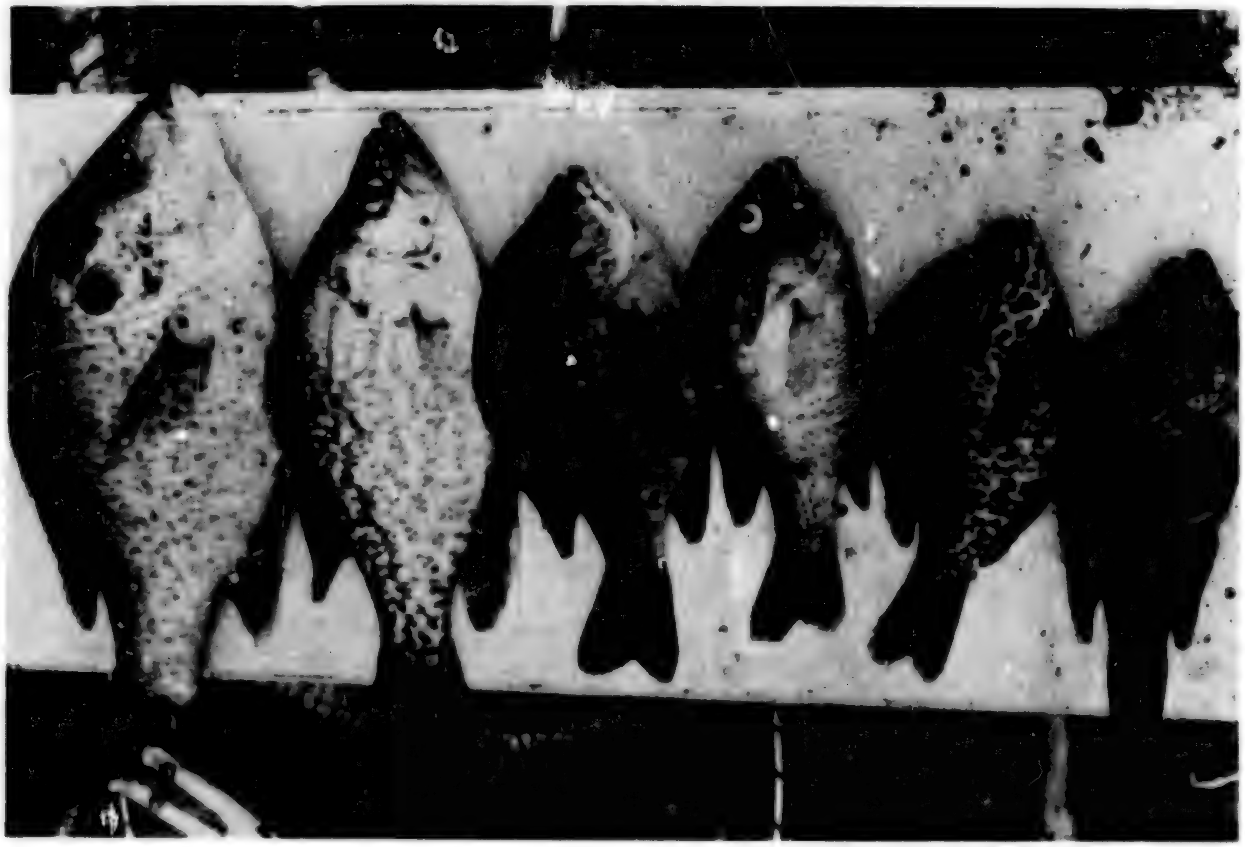

Figure 68. Common sunfish of the North Carolina Coastal Plain. From left: redear sunfish (Lepomis microlophus), black crappie, bluegill, redbreast sunfish, pumpkinseed, warmouth (courtesy of North Carolina Wildlife Resources Commission).

In the past, agricultural activity has often resulted in stream channelization, and commercial forestry has caused logging or stream floodplains. These processes severely affect the species composition and productivity of small streams (Huish and Pardue 1978). It is recommended that channelization or logging of pocosin streams be avoided where possible.

Agricultural and forestry practices in pocosins can detrimentally affect water quality in pocosin streams. Point and non-point inputs of silt, fertilizers, and pesticides/herbicides can all have negative effects on the stream food-chains on which fish depend. Water quality management is necessary when development occurs adjacent to pocosin streams.

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GLOSSARY

ammonia (NH_3) - Inorganic compound of nitrogen which is produced naturally by decomposition of organic nitrogen compounds and by anaerobic reduction of nitrate. In the dissolved state, the ammonium ion (NH_4^{+1}) is readily utilizable by aquatic plants, especially phytoplankton.

anaerobic - Without oxygen.

aquifer - Permeable layers of underground rock or sand that hold or transmit groundwater.

benthic - Pertaining to organisms that attach to, rest on, or live in the sediments at the bottom of lakes, streams, and oceans.

chlorophyll a - The most common of the several forms of chlorophyll found in plants. It can be used as an indicator of primary production or eutrophication in aquatic systems.

coliform bacteria - Gram-negative rod-shaped facultative anaerobic bacteria whose presence in water is indicative of fecal contamination.

colloid - A suspension in which the suspended particles are small disallowing separation by gravitational settling.

colloidal organic soil - Organic soils with very small particle sizes due to extensive decomposition, and with correspondingly large particle surface/volume ratios.

DBH - Diameter of trees at breast height (1.5 m or 5.0 ft). Used as an indicator of tree cover in vegetative analysis.

dendritic drainage basins - Drainage basins in which the principal water courses exhibit a multiple-branching pattern in response to erosional relief.

denitrification - A process whereby certain bacteria and fungi reduce nitrates to gaseous nitrogen under anaerobic conditions.

dissolved phosphorus - Phosphorus present in a sample in forms which will pass through a 0.45 m filter. Approximately synonymous with "filterable reactive phosphorus" or "orthophosphate."

endemic - A species restricted to a very limited geographic area.

environmental heterogeneity - The degree of diversity of geological types and/or biological communities within a given area.

epicormic bud - Dormant bud found under the bark of tree stems. These buds are the source of refoliation after fire in fire-adapted species such as pond pine.

Ericaceous - A member of the vascular plant family Ericaceae.

erosivity - A measure of a particular soils propensity for erosion.

evapotranspiration - The loss of moisture from soil due to the combined processes of evaporation from the soil surface and transpiration by plants.

extirpation - The complete elimination of an organism from a portion of its natural range.

fecal coliform bacteria - A coliform bacteria indicative of water contamination by the feces of humans or livestock.

fibric peat - Peat composed of plant remains so little decomposed that they are not destroyed by rubbing and their botanic origin can be determined.

filterable reactive phosphorus (FRP) - Phosphorus present in a sample in forms which will pass through a standard 0.45 μm filter and which reacts in a colorimetric test without preliminary hydrolysis or digestion. Approximately synonymous with "dissolved phosphorus" or "orthophosphate."

fire dis-climax - A plant community created from a climax plant community by fire disturbance. The terminology is that of the Clementsian mono-climax school of successional thought.

halocline - A gradient of salt concentration.

hemic peat - Peat composed of plant remains that have decomposed to the point that most fibers can be destroyed by rubbing and the botanic origin of one third of the material cannot be determined.

Histosols - The order of organic soils.

humilluvic horizon - The B horizon of some acid, organic soils that are farmed characterized by accumulation of illuvial humus leached from above.

inversely proportional - A condition where two things (variables) are reciprocaly related to one another by a constant (multiplier). A = constant/B. If A increases, then B decreases.

LD_{50} - The dose or concentration of a substance necessary to kill fifty percent of the affected organisms.

lithic contact - A boundary between soil and continuous, coherent, underlying material that has a hardness greater than three on Moh's scale.

loamy organic soil - Organic soils with mineral and organic particles that are macroscopic in size producing an identifiable texture.

mass-balance method - A method of determining quantities of inorganic nutrients or other materials which enter and leave a watershed. Using this method for determining phosphorus contributions of farmland to receiving streams, for example, would require information on farmland area, phosphorus concentrations and amounts of precipitation, levels of phosphorus in fertilizers and fertilizer application rates, phosphorus residence time in soils, and stream discharge rates and phosphorus concentrations.

mast - Nuts, seeds, and fruits eaten by wildlife.

mg/l - Milligrams per liter.

most probable number (MPN) - A statistical estimate of the number of bacteria in a given volume of water based on the number of positive results in a series of fermentation tubes (U.S. Public Health Service 1965, p. 3).

mull - a well decomposed organic soil that has been modified by drainage and biological activity.

nitrate (NO_3^{-1}) - inorganic, dissolved form of nitrogen readily utilizable by aquatic plants.

nitrite (NO_2^{-1}) - inorganic, dissolved form of nitrogen usually found in natural waters in much smaller concentrations than nitrate. In some analytical methods nitrate is reduced to nitrite; and if levels of nitrite are not predetermined separately, nitrite is included in the estimate of nitrate.

ontogeny - The course of development of an individual or system, here a plant community.

orthophosphate (PO_4^{-3}) - Inorganic phosphorus, mainly dissolved. The form of phosphorus most readily utilizable by aquatic plants.

overland runoff - The drainage of land by direct lateral water movement within the soil as opposed to drainage by water courses.

oxidation pond - A shallow pond used to treat wastewater, typically as a secondary treatment process for municipal sewage. Raw wastewater is delivered to the pond, where suspended solids settle out, inorganic nutrients are assimilated by algae, oxygenation takes place by wind mixing and algal growth, and ammonia is nitrified to nitrate.

pan evaporation - Evaporation from National Weather Service Class A pans used to estimate evapotranspiration. Class A pans are 1.2 m (4 ft) in diameter, 25 cm (10 in) deep, and placed 15 cm (6 in) off the ground.

paralithic contact - A boundary between soil and underlying coherent material that has a hardness of less than three on Moh's scale.

pesticides - A group of chemicals used in agriculture to control insect and plant pests.

pH - The negative log of the hydrogen ion concentration in solutions, a measure of acidity.

phaeophytin a - A breakdown product of chlorophyll a which can be used as an indicator of primary production or eutrophication in aquatic systems.

physiognomy - The external appearance of vegetation.

phytoplankton - Minute, floating plants found in the surface waters of lakes, streams, and oceans.

plastic soil - Soil that will continuously change shape under stress and will retain the impressed shape on removal of the stress.

postemergence - Referring to crops. The period of time after the crop plants break the surface of the soil.

ppm - Parts per million.

preemergence - Referring to crops. The period of time before the planted seeds germinate and break the surface of the ground.

proportional - A condition where two things (variables) are directly related to one another by a constant (multiplier). A = (constant)(B). If A increases, then B increases.

release - Enhanced plant growth due to elimination of competition from neighbors.

rhizome - A creeping underground stem.

roll-chopping - The removal of underbrush with a heavy drum fitted with blades, usually pulled by a tracked vehicle.

sapric peat - Peat composed of completely decomposed plant remains. No plant structures are apparent and botanical origin cannot be ascertained.

scarification - A type of soil preparation whereby many small grooves are created in the soil surface.

sclerophyllous leaves - Leaves with a thickened cuticle and internal reinforcement with lignin which produces a rigid, leathery texture.

serotinous cones - Pertaining to the cones of several species of pines which open and release their seeds after being exposed to extreme heat.

sheet flow - See overland runoff.

sorption (sorbed) - A collective term encompassing the processes of adsorption and absorption.

total Kjeldahl nitrogen (TKN) - Organically-bound nitrogen in the trinegative state, plus ammonia, as determined by the Kjeldahl analytical method. Approximately synonymous with "organic nitrogen."

total nitrogen - All nitrogen present in a sample regardless of form.

total phosphorus - All phosphorus present in a sample, regardless of form.

turbidity - Any condition in the atmosphere or bodies of water that reduces their transparency to radiation.

vfs - Very fine sand.

xeric shrub bog - A wetland with organic soils characterized by dense, shrubby sub-canopy vegetation and by periodic and extended intervals of soil dessication.

APPENDIX A

A REPRESENTATIVE LIST OF VASCULAR PLANTS OF POCOSINS AND POCOSIN ECOTONES[a]

Common Name	Scientific Name
American holly	*Ilex opaca*
Atlantic white cedar	*Chamaecyparis thyoides*
Autumnal Fimbristylis	*Fimbristylis autumnalis*
Bald cypress	*Taxodium distichum*
Bald rush	*Psilocarya nitens*
Bamboo-briar	*Smilax laurifolia*
Bartonia	*Bartonia verna*
Bayberry	*Myrica heterophylla*
Beakrush	*Rhynchospora alba*
Beakrush	*Rhynchospora cephalantha*
Beakrush	*Rhynchospora chalarocephala*
Beakrush	*Rhynchospora fascicularis*
Beakrush	*Rhynchospora gracilenta*
Beakrush	*Rhynchospora macrostachya*
Beakrush	*Rhynchospora wrightiana*
Bitter gallberry	*Ilex glabra*
Black gum	*Nyssa sylvatica* var. *biflora*
Blackberry	*Rubus* sp
Bladderwort	*Utricularia biflora*
Bladderwort	*Utricularia inflata*
Bladderwort	*Utricularia purpurea*
Blue flag	*Iris virginica*
Bog buttons	*Lachnocaulon anceps*
Bracken fern	*Pteridium aquilinum*
Brazilian Richardia	*Richardia brasiliensis*
Broomsedge	*Andropogon virginicus*
Butterwort	*Pinguicula lucea*
Buttonbush	*Cephalanthus occidentalis*
Buttonweed	*Diodia teres*
Catesby's gentain	*Gentiana catesbaei*
Centella	*Centella asiatica*
Cinnamon fern	*Osmunda cinnamomea*
Climbing hempweed	*Mikania scandens*
Common cat-tail	*Typha latifolia*
Cotton grass	*Eriophorum virginicum*
Creeping blueberry	*Vaccinium crassifolium*
Creeping rush	*Juncus repens*
Crested fringed-orchid	*Platanthera cristata*
Dahoon	*Ilex myrtifolia*
Daisey fleabane	*Erigeron vernus*
Dangleberry	*Gaylussacia frondosa*
Dichromena	*Dichromena latifolia*
Dodder	*Cuscuta compacta*
Dwarf azalea	*Rhododendron atlanticum*
Dwarf huckleberry	*Gaylussacia dumosa*
Elderberry	*Sambucus canadensis*
False loosestrife	*Ludwigia linearis*
False loosestrife	*Ludwigia pilosa*
Fetterbush	*Leucothoe racemosa*
Fetterbush	*Lyonia lucida*
Foxtail clubmoss	*Lycopodium alopecuroides*
Golden-crest	*Lophiola americana*
Golden club	*Orontium aquaticum*
Greenbriar	*Smilax auriculata*
Greenbriar	*Smilax glauca*
Greenbriar	*Smilax pseudo-china*
Greenbriar	*Smilax walteri*
Heartleaf	*Asarum arifolium*
Hedge hyssop	*Gratiola pilosa*
Highbush blueberry	*Vaccinium corymbosum*
Hog-fennel	*Oxypolis filiformis*
Hog-fennel	*Oxypolis ternata*
Honeycup	*Zenobia pulverulenta*
Hooded pitcher-plant	*Sarracenia minor*
Horse sugar	*Symplocos tinctoria*
Horsetail	*Equisetum arvense*
Iris	*Iris tridentata*

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[a] Sources for this list are: Kologiski (1977), Snyder (1977), Ashton and Ashton (1979), McDonald and Ash (1981), McDonald et al. (1981). Scientific plant names in appendices conform to the National List of Scientific Plant Names (Soil Conservation Service 1982). Common names conform to Radford et al. (1968).

Common Name	Scientific Name
Lamb-kill	Kalmia carolina
Leatherleaf	Chamaedaphne calyculata
Leucothoe	Leucothoe axillaris
Lobelia	Lobelia nuttallii
Loblolly bay	Gordonia lasianthus
Loblolly pine	Pinus taeda
Longleaf pine	Pinus palustris
Longleaved sundew	Drosera filiformis
Male-blueberry	Lyonia ligustrina
Many-headed rush	Juncus polycephalus
Margined rush	Juncus marginatus
Marsh-fleabane	Pluchea foetida
Mermaid-weed	Proserpinaca pectinata
Meadow beauty	Rhexia aristosa
Mistletoe	Phoradendron serotinum
Muscadine	Vitis rotundifolia
Netted chain-fern	Woodwardia areolata
Oldenlandia	Oldenlandia uniflora
Panic-grass	Panicum dichotomiflorum
Path rush	Juncus tenuis
Pennywort	Hydrocotyle verticillata var. triradiata
Pickerelweed	Pontederia cordata
Pine-barren gentain	Gentiana autumnalis
Pinxter-flower	Rhododendron periclymenoides
Pipewort	Eriocaulon compressum
Pitcher-plant	Sarracenia purpurea
Pond cypress	Taxodium distichum-nutans
Pond pine	Pinus serotina
Pyxie moss	Pyxidanthera barbulata
Red bay	Persea borbonia
Red chokeberry	Aronia arbutifolia
Red maple	Acer rubrum
Redroot	Lachnanthes caroliniana
Resurrection fern	Polypodium polypodioides
Rough-leaf loosestrife	Lysimachia asperulifolia
Royal fern	Osmunda regalis var. spectabilis
Rush	Juncus acuminatus
Rush-featherling	Pleea tenuifolia
Sabatia	Sabatia difformis
Sedge	Carex elliottii
Sedge	Carex folliculata var. australis
Sedge	Carex glaucescens
Sedge	Carex walterana
Short-leaved milkwort	Polygala brevifolia
Smartweed	Polygonum hydropiperoides
Smartweed	Polygonum punctatum
Smooth winterberry	Ilex laevigata
Sparkleberry	Vaccinium arboreum
Spatterdock	Nuphar luteum
Spike rush	Eleocharis equisetoides
Spike rush	Eleocharis microcarpa
Spike rush	Eleocharis tuberculosa
St. John's-wort	Hypericum canadense
St. John's-wort	Hypericum cistifolium
St. John's-wort	Triadenum virginicum
Storax	Styrax american
Sundew	Drosera capillaris
Sundew	Drosera intermedia
Swamp ash	Fraxinus caroliniana
Swamp azalea	Rhododendron viscosum
Swamp haw	Viburnum nudum
Sweet gallberry	Ilex coriacea
Sweet pepperbush	Clethra alnifolia
Sweet pitcher-plant	Sarracenia rubra
Sweetbay	Magnolia virginiana
Sweetgum	Liquidambar styraciflua
Switchcane	Arundinaria gigantea
Syngonanthus	Syngonanthus flavidulus
Ten-angled pipewort	Eriocaulon decangulare
Three-way sedge	Dulichium arundinaceum
Titi	Cyrilla racemiflora
Trumpets	Sarracenia flava
Tupelo gum	Nyssa aquatica
Two-flowered Burmannia	Burmannia biflora
Two-flowered rush	Juncus biflorus
Two-parted rush	Juncus dichotomus
Umbrella grass	Fuirena squarrosa
Venus' fly trap	Dionaea muscipula
Virginia buttonweed	Diodia virginiana
Virginia chain-fern	Woodwardia virginica
Virginia willow	Itea virginica
Water-lily	Nymphaea odorata
Wax myrtle	Myrica cerifera
Wells' pyxie moss	Pyxidanthera brevifolia
White arum	Peltandra sagittifolia
White wicky	Kalmia cuneata
Winged sumac	Rhus copallinum
Wintergreen	Gaultheria procumbens
Witch-alder	Fothergilla gardenii
Yellow jessamine	Gelsemium sempervirens
Yellow-eyed grass	Xyris ambigua
Yellow-eyed grass	Xyris baldwiniana
Yellow-eyed grass	Xyris caroliniana
Yellow-eyed grass	Xyris fimbriata

APPENDIX B

VASCULAR PLANTS OF POCOSINS AND RELATED FRESHWATER WETLANDS THAT ARE THREATENED OR ENDANGERED[a]

Common Name	Scientific Name
Carolina goldenrod	*Solidago stricta*
Carolina trillium	*Trillium pusillum*
Cooley's meadowrue	*Thalictrum cooleyi*
Dwarf bladderwort	*Utricularia olivacea*
Lewis' heart leaf	*Asarum lewisii*
Loose watermilfoil	*Myriophyllum laxum*
Resinous joe-pye weed*	*Eupatorium resinosum*
Riverbank sandreed*	*Calamovilfa brevipilis*
Rough-leaf loosestrife*	*Lysimachia asperulifolia*
Sarvis holly*	*Ilex amelanchier*
Southern rein-orchid	*Platanthera flava*
Southern spicebush*	*Lindera melissifolia*
Spring-flowering goldenrod	*Solidago verna*
Sweet pitcher-plant	*Sarracenia rubra*
Venus' fly-trap	*Dionea muscipula*
Wells' pyxie moss*	*Pyxidanthera brevifolia*
White wicky*	*Kalmia cuneata*
Wireleaf dropseed	*Sporobolus teretifolius*
Yellow fringeless-orchid	*Platanthera integra*

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[a] Species marked with an asterisk are legally protected in North Carolina under the North Carolina Protection and Conservation Act of 1979. Other species are listed in *Endangered and Threatened Plants and Animals of North Carolina* (J.E. Cooper, et al., eds. 1977).

APPENDIX C

A REPRESENTATIVE LIST OF VERTEBRATE FAUNA OF POCOSINS, POCOSIN ECOTONES AND ADJACENT WATERS[a]

Common Name	Scientific Name
FISH	
Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Atlantic croaker	*Micropogonias undulatus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic needlefish	*Strongylura marina*
Atlantic spadefish	*Chaetodipterus faber*
Atlantic thread herring	*Opisthonema oglinum*
Banded killifish	*Fundulus diaphanus*
Banded sunfish	*Enneacanthus obesus*
Bay anchovy	*Anchoa mitchilli*
Blackcheek tonguefish	*Symphurus plagiusa*
Black crappie	*Pomoxis nigromaculatus*
Blackbanded sunfish	*Enneacanthus chaetodon*
Blueback herring	*Alosa aestivalis*
Bluefish	*Pomatomus saltatrix*
Bluegill	*Lepomis macrochirus*
Bluespotted sunfish	*Enneacanthus gloriosus*
Bowfin	*Amia calva*
Brown bullhead	*Ictalurus nebulosus*
Bullnose ray	*Myliobatis freminvillei*
Carp	*Cyprinus carpio*
Chain pickerel	*Esox niger*
Channel catfish	*Ictalurus punctatus*
Cownose ray	*Rhinoptera bonasus*
Crevalle jack	*Caranax hippos*
Dusky pipefish	*Syngnathus floridae*
Dusky shiner	*Notropis cummingsae*
Eastern mudminnow	*Umbra pygmaea*
Feather blenny	*Hypsoblennius hentzi*
Flier	*Centrarchus macropterus*
Gizzard shad	*Dorosoma cepedianum*
Golden shiner	*Notemigonus crysoleucas*
Green goby	*Microgobius thalassinus*
Hogchoker	*Trinectes maculatus*
Ironcolor shiner	*Notropis chalybaeus*
Johnny darter	*Etheostoma nigrum*
Ladyfish	*Elops saurus*
Lake chubsucker	*Erimyzon sucetta*
Largemouth bass	*Micropterus salmoides*
Longnose gar	*Lepisosteus osseus*
Marked goby	*Gobionellus stigmaticus*
Mosquitofish	*Gambusia affinis*
Mud sunfish	*Acantharchus pomotis*
Mummichog	*Fundulus heteroclitus*
Naked goby	*Gobiosoma bosci*
Northern pipefish	*Syngnathus fuscus*
Pinfish	*Lagodon rhomboides*
Pirate perch	*Aphredoderus sayanus*
Pumpkinseed	*Lepomis gibbosus*
Pygmy killifish	*Leptolucania ommata*
Rainwater killifish	*Lucania parva*
Redbreast sunfish	*Lepomis auritus*
Red drum	*Sciaenops ocellata*
Redfin pickerel	*Esox americanus americanus*
Rough silverside	*Membras martinica*
Satinfin shiner	*Notropis analostanus*
Sawcheek darter	*Etheostoma serriferum*
Silver jenny	*Eucinostomus gula*
Silver perch	*Bairdiella chrysoura*
Silvery minnow	*Hybognathus nuchalis*
Skilletfish	*Gobiesox strumosus*

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[a] Sources for this list are: Coastal Zone Resources Corporation (1976), Allen et al. (1979), Potter (1982), and U.S. Fish and Wildlife Service (in prep.). Nomenclature in all animal lists follows Robins et al. (1980), fish; Collins et al. (1982), amphibians and reptiles; American Ornithologists' Union (1982), birds; Jones et al. (1979), mammals.

Common Name	Scientific Name
Southern flounder	*Paralichthys lethostigma*
Southern studfish	*Fundulus stellifer*
Spanish mackerel	*Scomberomorus maculatus*
Speckled worm eel	*Myrophis punctatus*
Spot	*Leiostomus xanthurus*
Spottail shiner	*Notropis hudsonius*
Spotted seatrout	*Cynoscion nebulosus*
Starhead topminnow	*Fundulus notti*
Striped bass	*Morone saxatilis*
Striped killifish	*Fundulus majalis*
Striped mullet	*Mugil cephalus*
Summer flounder	*Paralichthys dentatus*
Swamp darter	*Etheostoma fusiforme*
Swampfish	*Chologaster cornuta*
Tadpole madtom	*Noturus gyrinus*
Tessellated darter	*Etheostoma olmstedi*
Threadfin shad	*Dorosoma petenense*
Tidewater silverside	*Menidia beryllina*
Warmouth	*Lepomis gulosus*
Weakfish	*Cynoscion regalis*
White catfish	*Ictalurus catus*
White perch	*Morone americanus*
Yellow bullhead	*Ictalurus natalis*
Yellow perch	*Perca flavescens*

REPTILES AND AMPHIBIANS

Common Name	Scientific Name
American alligator	*Alligator mississippiensis*
Banded water snake	*Nerodia fasciata fasciata*
Barking treefrog	*Hyla gratiosa*
Black racer	*Coluber constrictor constrictor*
Black rat snake	*Elaphe obsoleta*
Brimley's chorus frog	*Pseudacris brimleyi*
Broadhead skink	*Eumeces laticeps*
Brown snake	*Storeria dekayi*
Brown water snake	*Nerodia taxispilota*
Bullfrog	*Rana catesbeiana*
Carolina crawfish frog	*Rana areolata capito*
Carolina salt marsh snake	*Nerodia sipedon williamengelsi*
Carolina swamp snake	*Seminatrix pygaea paludis*
Carpenter frog	*Rana virgatipes*
Common snapping turtle	*Chelydra serpentina serpentina*
Copperhead	*Agkistrodon contortrix*
Corn snake	*Elaphe guttata guttata*
Diamondback terrapin	*Malaclemys terrapin*
Dusky salamander	*Desmognathus fuscus/ auriculatus*
Eastern box turtle	*Terrapene carolina carolina*
Eastern cottonmouth	*Agkistrodon piscivorus piscivorus*
Eastern diamondback rattle-snake	*Crotalus adamanteus*
Eastern garter snake	*Thamnophis sirtalis sirtalis*
Eastern glass lizard	*Ophisauris ventralis*
Eastern hognose snake	*Heterodon platyrhinos*
Eastern kingsnake	*Lampropeltis getulus getulus*
Eastern mud salamander	*Pseudotriton montanus montanus*
Eastern mud snake	*Farancia abacura abacura*
Eastern mud turtle	*Kinosternon subrubrum subrubrum*
Eastern narrowmouth toad	*Gastrophryne carolinensis*
Eastern painted turtle	*Chrysemys picta picta*
Eastern ribbon snake	*Thamnophis sauritus sauritus*
Eastern river cooter	*Pseudemys concinna concinna*
Eastern spadefoot	*Scaphiopus holbrooki holbrooki*
Eastern worm snake	*Carphophis amoenus amoenus*
Five-lined skink	*Eumeces fasciatus*
Florida cooter	*Pseudemys floridana floridana*
Fowler's toad	*Bufo woodhousei fowleri*
Glossy crafish snake	*Regina rigida rigida*
Gray treefrog	*Hyla chrysoscelis/versicolor*
Greater siren	*Siren lacertina*
Green anole	*Anolis carolinensis*
Green frog	*Rana clamitans melanota*
Green treefrog	*Hyla cinerea*
Ground skink	*Scincella lateralis*
Little grass frog	*Limnaoedus ocularis*
Mabee's salamander	*Ambystoma mabeei*
Many-lined salamander	*Stereochilus marginatus*
Marbled salamander	*Ambystoma opacum*
Northern fence lizard	*Sceloporus undulatus hyacinthinus*
Northern redbelly snake	*Storeria occipitomaculata occipitomaculata*
Northern scarlet snake	*Cemophora coccinea copei*
Northern spring peeper	*Hyla crucifer crucifer*
Northern water snake	*Nerodia sipedon sipedon*
Oak toad	*Bufo quercicus*
Pickerel frog	*Rana palustris*

Common Name	Scientific Name
Pine woods snake	*Rhadinaea flavilata*
Pine woods treefrog	*Hyla femoralis*
Rainbow snake	*Farancia erytrogramma erytrogramma*
Redback salamander	*Plethodon cinereus*
Redbelly turtle	*Pseudemys rubriventris rubriventris*
Redbelly water snake	*Nerodia erythrogaster erythrogaster*
Red-spotted newt	*Notopthalmus viridescens viridescens*
Rough earth snake	*Virginia striatula*
Rough green snake	*Opheodrys aestivus*
Scarlet kingsnake	*Lampropeltis triangulum elapsoides*
Six-lined racerunner	*Cnemidophorus sexlineatus sexlineatus*
Slimy salamander	*Plethodon glutinosus*
Southeastern five-lined skink	*Eumeces inexpectatus*
Southern cricket frog	*Acris gryllus gryllus*
Southern leopard frog	*Rana sphenocephala*
Southern ringneck snake	*Diadophis punctatus punctatus*
Southern toad	*Bufo terrestris*
Spotted turtle	*Clemmys guttata*
Squirrel treefrog	*Hyla squirella*
Stinkpot	*Sternotherus odoratus*
Timber rattlesnake	*Crotalus horridus*
Two-toed amphiuma	*Amphiuma means*
Yellowbelly slider	*Pseudemys scripta scripta*

BIRDS

Common Name	Scientific Name
Acadian flycatcher	*Empidonax virescens*
American bittern	*Botaurus lentiginosus*
American black duck	*Anas rubripes*
American coot	*Fulica americana*
American crow	*Corvus brachyrhynchos*
American goldfinch	*Carduelis tristis*
American kestrel	*Falco sparverius*
American redstart	*Setophaga ruticilla*
American robin	*Turdus migratorius*
American wigeon	*Anas americana*
American woodcock	*Scolopax minor*
Anhinga	*Anhinga anhinga*
Bald eagle	*Haliaeetus leucocephalus*
Bachman's sparrow	*Aimophila aestivalis*
Barn swallow	*Hirundo rustica*
Barred owl	*Strix varia*
Belted kingfisher	*Ceryle alcyon*
Black-and-white warbler	*Mniotilta varia*
Black-crowned night-heron	*Nycticorax nycticorax*
Black rail	*Laterallus jamaicensis*
Black skimmer	*Rynchops niger*
Black-throated green warbler	*Dendroica virens*
Blue-gray gnatcatcher	*Polioptila caerulea*
Blue grosbeak	*Guiraca caerulea*
Blue jay	*Cyanocitta cristata*
Blue-winged teal	*Anas discors*
Boat-tailed grackle	*Quiscalus major*
Bobolink	*Dolichonyx oryzivorus*
Brown-headed cowbird	*Molothrus ater*
Brown-headed nuthatch	*Sitta pusilla*
Brown thrasher	*Toxostoma rufum*
Bufflehead	*Bucephala albeola*
Canada goose	*Branta canadensis*
Canvasback	*Aythya valisineria*
Carolina chickadee	*Parus carolinensis*
Carolina wren	*Thryothorus ludovicianus*
Caspian tern	*Sterna caspia*
Cattle egret	*Bubulcus ibis*
Cedar waxwing	*Bombycilla cedrorum*
Chimney swift	*Chaetura pelagica*
Chipping sparrow	*Spizella passerina*
Chuck-will's-widow	*Caprimulgus carolinensis*
Common goldeneye	*Bucephala clangula*
Common grackle	*Quiscalus quiscula*
Common merganser	*Mergus merganser*
Common moorhen	*Gallinula chloropus*
Common nighthawk	*Chordeiles minor*
Common tern	*Sterna hirundo*
Common yellowthroat	*Geothlypis trichas*
Cooper's hawk	*Accipiter cooperii*
Dark-eyed junco	*Junco hyemalis*
Double-crested cormorant	*Phalacrocorax auritus*
Downy woodpecker	*Picoides pubescens*
Eastern bluebird	*Sialia sialis*
Eastern kingbird	*Tyrannus tyrannus*
Eastern meadowlark	*Sturnella magna*
Eastern phoebe	*Sayornis phoebe*
Eastern screech owl	*Otus asio*
Eastern wood-pewee	*Contopus virens*
European starling	*Sturnus vulgaris*
Evening grosbeak	*Hesperiphona vespertina*

Common Name	Scientific Name
Field sparrow	Spizella pusilla
Fish crow	Corvus ossifragus
Fox sparrow	Passerella iliaca
Gadwall	Anas strepera
Golden-crowned kinglet	Regulus satrapa
Gray catbird	Dumetella carolinensis
Great black-backed gull	Larus marinus
Great blue heron	Ardea herodias
Great crested flycatcher	Myiarchus crinitus
Great egret	Casmerodius albus
Great horned owl	Bubo virginianus
Greater scaup	Aythya marila
Green-backed heron	Butorides striatus
Green-winged teal	Anas crecca
Gull-billed tern	Sterna nilotica
Hairy woodpecker	Picoides villosus
Hermit thrush	Catharus guttatus
Herring gull	Larus argentatus
Hooded merganser	Lophodytes cucullatus
Hooded warbler	Wilsonia citrina
Horned lark	Eremophila alpestris
House sparrow	Passer domesticus
House wren	Troglodytes aedon
Indigo bunting	Passerina cyanea
Kentucky warbler	Oporornis formosus
Killdeer	Charadrius vociferus
King rail	Rallus elegans
Laughing gull	Larus atricilla
Least bittern	Ixobrychus exilis
Least tern	Sterna antillarvum
Lesser scaup	Aythya affinis
Louisiana waterthrush	Seiurus motacilla
Mallard	Anas platyrhynchos
Marsh wren	Cistothorus palustris
Mourning dove	Zenaida macroura
Northern bobwhite	Colinus virginianus
Northern cardinal	Cardinalis cardinalis
Northern flicker	Colaptes auratus
Northern harrier	Circus Cyaneus
Northern mockingbird	Mimus polyglottos
Northern parula	Parula americana
Northern pintail	Anas acuta
Northern rough-winged swallow	Stelgidopteryx serripennis
Northern saw-whet owl	Aegolius acadicus
Northern shoveler	Anas clypeata
Orange-crowned warbler	Vermivora celata

Common Name	Scientific Name
Orchard oriole	Icterus spurius
Osprey	Pandion haliaetus
Ovenbird	Seiurus aurocapillus
Palm warbler	Dendroica palmarum
Pied-billed grebe	Podilymbus podiceps
Pileated woodpecker	Dryocopus pileatus
Pine siskin	Carduelis pinus
Pine warbler	Dendroica pinus
Prairie warbler	Dendroica discolor
Prothonatary warbler	Protonotaria citrea
Purple martin	Progne subis
Red-bellied woodpecker	Melanerpes carolinus
Red-breasted merganser	Mergus serrator
Red-breasted nuthatch	Sitta canadensis
Red-cockaded woodpecker	Picoides borealis
Red-eyed vireo	Vireo olivaceus
Redhead	Aythya americana
Red-headed woodpecker	Melanerpes erythrocephalus
Red-shouldered hawk	Buteo lineatus
Red-tailed hawk	Buteo jamaicensis
Red-winged blackbird	Agelaius phoeniceus
Ring-billed gull	Larus delawarensis
Rock dove	Columba livia
Royal tern	Sterna maxima
Ruby-crowned kinglet	Regulus calendula
Ruby-throated hummingbird	Archilochus colubris
Ruddy duck	Oxyura jamaicensis
Rufous-sided towhee	Pipilo erythrophthalmus
Rusty blackbird	Euphagus carolinus
Savannah sparrow	Passerculus sandwichensis
Sedge wren	Cistothorus platensis
Snow goose	Chen caerulescens
Solitary sandpiper	Tringa solitaria
Solitary vireo	Vireo solitarius
Song sparrow	Melospiza melodia
Summer tanager	Piranga rubra
Swainson's warbler	Limnothlypis swainsonni
Swamp sparrow	Melospiza georgiana
Tree swallow	Tachycineta bicolor
Tufted titmouse	Parus bicolor
Tundra swan	Olor columbianus
Turkey vulture	Cathartes aura
Virginia rail	Rallus limicola
Whip-poor-will	Caprimulgus vociferus
White-breasted nuthatch	Sitta carolinensis
White-eyed vireo	Vireo griseus
White-throated sparrow	Zonotrichia albicollis

Common Name	Scientific Name
Wood duck	*Aix sponsa*
Wood thrush	*Hylocichla mustelina*
Worm-eating warbler	*Helmitheros vermivorus*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Yellow-billed cuckoo	*Coccyzus americanus*
Yellow-breasted chat	*Icteria virens*
Yellow-rumped warbler	*Dendroica coronata*
Yellow-throated warbler	*Dendroica dominica*
Yellow warbler	*Dendroica petechia*

MAMMALS

Common Name	Scientific Name
Beaver	*Castor canadensis*
Big brown bat	*Eptesicus fuscus*
Black bear	*Ursus americanus*
Black rat	*Rattus rattus*
Bobcat	*Felis lynx*
Cotton mouse	*Peromyscus gossypinus*
Eastern big-eared bat	*Plecotus rafinesqueii*
Eastern chipmunk	*Tamias striatus*
Eastern cottontail	*Sylvilagus floridanus*
Eastern fox squirrel	*Sciurus niger*
Eastern gray squirrel	*Sciurus carolinensis*
Eastern harvest mouse	*Reithrodontomys humulis*
Eastern mole	*Scalopus aquaticus*
Eastern pipistrelle	*Pipistrellus subflavus*
Evening bat	*Nycticeius humeralis*
Golden mouse	*Ochrotomys nuttalli*
Gray fox	*Urocyon cinereoargenteus*
Hispid cotton rat	*Sigmodon hispidus*
Hoary bat	*Lasiurus cinereus*
House mouse	*Mus musculus*
Keen's myotis	*Myotis keenii*
Least shrew	*Cryptotis parva*
Little brown myotis	*Myotis lucifugus*
Long-tailed weasel	*Mustela frenata*
Marsh rabbit	*Sylvilagus palustris*
Marsh rice rat	*Oryzomys palustris*
Meadow jumping mouse	*Zapus hudsonius*
Meadow vole	*Microtus pennsylvanicus*
Mink	*Mustela vison*
Muskrat	*Ondatra zibethicus*
Northern yellow bat	*Lasiurus intermedius*
Norway rat	*Rattus norvegicus*
Nutria	*Myocastor coypus*
Opossum	*Didelphis virginiana*
Raccoon	*Procyon lotor*
Red bat	*Lasiurus borealis*
Red fox	*Vulpes vulpes*
River otter	*Lutra canadensis*
Seminole bat	*Lasiurus seminolus*
Short-tailed shrew	*Blarina brevicauda*
Silver-haired bat	*Lasionycteris noctivagans*
Southeastern shrew	*Sorex longirostris*
Southern bog lemming	*Synaptomys cooperi*
Southern flying squirrel	*Glaucomys volans*
Star-nosed mole	*Condylura cristata*
Striped skunk	*Mephitis mephitis*
White-footed mouse	*Peromyscus leucopus*
White-tailed deer	*Odocoileus virginianus*
Woodland vole	*Microtus pinetorum*

APPENDIX D

TERRESTRIAL VERTEBRATES OF POCOSINS AND RELATED FRESHWATER WETLANDS THAT ARE ENDANGERED OR OF SPECIAL CONCERN[a]

Common Name	Scientific Name
Alligator	*Alligator mississippiensis*
American black duck	*Anas rubripes*
Anhinga	*Anhinga anhinga*
Bachman's sparrow*	*Aimophila aestivalis*
Bald eagle	*Haliaeetus leucocephalus*
Beaver	*Castor canadensis*
Black-and-white warbler	*Mniotilta varia*
Black bear	*Ursus americanus*
Black-throated green warbler	*Dendroica virens*
Carolina crawfish frog	*Rana areolata capito*
Dismal Swamp meadow vole	*Microtus pennsylvanicus nigrans*
Dismal Swamp short-tailed shrew*	*Blarina brevicauda telmalestes*
Dismal Swamp southeastern shrew*	*Sorex longirostris fisheri*
Double-crested cormorant	*Phalacrocorax auritus floridanus*
Eastern diamondback rattlesnake	*Crotalus adamanteus*
Least bittern	*Ixobrychus exilis*
Neuse River waterdog*	*Necturus lewisi*
Osprey	*Pandion haliaetus*
Pine barrens tree frog*	*Hyla andersoni*
Prothonotary warbler	*Protonotaria citrea*
Red-cockaded woodpecker	*Picoides borealis*
Red-shouldered hawk	*Buteo lineatus*
Southern bog lemming*	*Synaptomys cooperi*
Swainson's warbler	*Limnothlypis swainsonii*
Worm-eating warbler	*Helmitheros vermivorus*

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[a] Species that are marked with an asterisk receive Federal protection under the Endangered Species Act of 1973. All other species are listed in Cooper et al. (1977).

APPENDIX E

GAME SPECIES INDIGENOUS TO POCOSINS OR RELATED FRESHWATER WETLANDS

Common Name	Scientific Name
American woodcock	*Scolopax minor*
Black bear	*Ursus americanus*
Beaver	*Castor canadensis*
Bobcat	*Felis lynx*
Clapper rail	*Rallus longirostris*
Eastern cottontail	*Sylvilagus floridanus*
Gray fox	*Urocyon cinereoaraenteus*
Gray squirrel	*Sciurus carolinensis*
Longtail weasel	*Mustella frenata*
Marsh rabbit	*Sylvilagus palustris*
Mink	*Mustella vison*
Mourning dove	*Zenaida macroura*
Muskrat	*Ondatra zibethicus*
Northern bobwhite	*Colinus virginianus*
Opossum	*Didelphis virginiana*
Raccoon	*Procyon lotor*
River otter	*Lutra canadensis*
Waterfowl	*Anatidae*
Whitetail deer	*Odocoileus virginianus*

APPENDIX F

NATIONAL AND NORTH CAROLINA PRIVATE ORGANIZATIONS THAT CAN RECEIVE AND MANAGE GIFTS OF LAND[a]

The Nature Conservancy

Box 805
Chapel Hill, North Carolina 27514
or
1800 North Kent Street
Arlington, Virginia 22209

The Nature Conservancy, with its North Carolina branch, is a national nonprofit organization that has helped preserve nearly 1.5 million acres in the United States--including over 100,000 acres of significant natural land in North Carolina. TNC is dedicated to conservation through private action. In some situations, TNC sponsors local project committees to help acquire and manage natural areas.

National Audubon Society

Southeast Regional Office
Post Office Box 1268
Charleston, South Carolina 29402
or
950 Third Avenue
New York, New York 10022

National Audubon Society and its seven North Carolina local chapters are capable of acquiring and managing wildlife sanctuaries. NAS now owns one large preserve on the North Carolina coast; and one of its local chapters administers a community natural area. Audubon's goals are to protect wildlife resources, provide environmental education and improve our natural environment.

National Wildlife Federation

1412 Sixteenth Street, N.W.
Washington, D.C. 20036

National Wildlife Federation is a national organization of wildlife conservationists that promotes wildlife and habitat protection and conservation education. Its "Common Heritage Program" receives funds and holds land for wildlife refuges. NWF provides information to private landowners for habitat management.

Trust for Public Land

Southeast Regional Office
1300 Executive Center Drive
Suite 308
Tallahassee, Florida 32301
or
82 Second Street
San Francisco, California 94105

This national nonprofit organization specializes in acquiring and preserving open space lands on behalf of the public. TPL has helped establish several local land trusts in other states, including urban land trusts.

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[a] From Roe and Sussman (1979).

North Carolina Botanical Garden Foundation

c/o North Carolina Botanical Garden
100 Totten Center
Laurel Hill Road
Chapel Hill, North Carolina 27514

This foundation is the support organization for the North Carolina Botanical Garden and is empowered to acquire and hold unique natural lands. The foundation focuses its preservation efforts on unique natural areas--rare and unusual plant species and threatened habitats. It has acquired several important botanical areas throughout the state.

Conservation Foundation of North Carolina

c/o CCNC
307 Granville Road
Chapel Hill, North Carolina 27514

This nonprofit foundation wing of the Conservation Council of North Carolina can receive land. It is acquiring the MacLamrock historic and recreational area in Rockingham County. The CF and CCNC are engaged in a wide variety of conservation interests.

North Carolina Land Trustees of America, Incorporated

Turkey Farm Road, Route 2
Chapel Hill, North Carolina 27514

The North Carolina Land Trustees is a nonprofit corporation seeking to conserve valuable land. It offers to dedicate rural and urban properties to innovative uses by conscientious trustee residents. NCLT encourages land stewards to develop land in ways that emphasize self-reliance and conservation.

APPENDIX G

SOME PRINCIPAL NATIVE WILDLIFE FOOD PLANTS OF POCOSINS AND RELATED FRESHWATER WETLANDS OR WETLAND MARGINS

Common Name	Scientific Name	Common Name	Scientific Name
American beech	*Fagus grandifolia*	Lespedeza	*Lespedeza* spp.
American holly	*Ilex opaca*	Oak	*Quercus* spp.
Bitter gallberry	*Ilex glabra*	Pawpaw	*Asimina* spp.
Blackberry	*Rubus* spp.	Arrow-arum	*Peltandra virginica*
Black gum	*Nyssa sylvatica*	Persimmon	*Diospyros virginiana*
Blueberry	*Vaccinium spp.*	Pine	*Pinus* spp.
Bracken fern	*Pteridium aquilinum*	Poke	*Phytolacca americana*
Cane	*Arundinaria gigantea*	Red bay	*Persea borbonia*
Chinquapin	*Castanea pumila*	Red chokeberry	*Aronia arbutifolia*
Crab-apple	*Malus angustifolia*	Red maple	*Acer rubrum*
Dahoon	*Ilex cassine*	Swamp cottonwood	*Populus heterophylla*
Dogwood	*Cornus florida*	Swamp haw	*Viburnum nudum*
Grape	*Vitis* spp.	Sweet bay	*Magnolia virginiana*
Grass	Poaceae (Gramineae)	Sweet gallberry	*Ilex coriacea*
Greenbriar	*Smilax* spp.	Sweet gum	*Liquidambar styraciflua*
Hawthorn	*Crataegus* spp.	Sweet pepperbush	*Clethra alnifolia*
Hickory	*Carya* spp.	Titi	*Cyrilla racemiflora*
Honeycup	*Zenobia pulverulenta*	Tupelo gum	*Nyssa aquatica*
Huckleberry	*Gaylussacia* spp.	Winged sumac	*Rhus copallina*
Leatherleaf	*Chaemaedaphne calyculata*	Winterberry	*Ilex verticillata*

APPENDIX H

USEFUL NATIVE AND INTRODUCED PLANTS FOR WILDLIFE MANAGERS OF ALTERED POCOSINS AND RELATED FRESHWATER WETLANDS[a]

Common Name	Scientific Name	Use		
		Cover	Food	Windbreak
Aaronsbeard	*Hypericum calycinum*	X		
American beech	*Fagus grandifolia*		X	X
Autumn olive	*Elaeagnus umbellata*		X	X
Bahia grass	*Paspalum notatum*	X		
Bayberry	*Myrica pennsylvanica*	X	X	X
Beargrass	*Yucca filmentosa*	X		
Beauty-berry	*Callicarpa americana*	X	X	
Bermuda grass	*Cynodon dactylon*	X		
Bigleaf winter-creeper	*Eyonymus fortunei*	X		
Bitter gallberry	*Ilex glabra*	X	X	X
Browntop millet	*Panicum ramosum*	X	X	
Bugle flower	*Ajuga reptans*	X		
Carolina jessamine	*Gelsemium sempervirens*	X	X	
Carolina laurel-cherry	*Prunus caroliniana*		X	X
Chinese chestnut	*Castanea mollissima*		X	X
Corn	*Zea mays*		X	
Cottonwood, poplar	*Populus* spp.		X	X
Crimson clover	*Trifolium incarnatum*	X	X	
Day-lilly	*Hemerocallis spp.*	X		
Dwarf forsythia	*Forsythia arnoldi*	X		
Elderberry	*Sambucus canadensis*	X	X	
English ivy	*Hedera helix*	X		
Evergreen euonymus	*Euonymus japonicus*			X
Everlasting pea	*Lathyrus latifolius*	X	X	
Firethorn	*Pyracantha coccinea*		X	X
Gold flower	*Hypericum moseranum*	X		
Grape	*Vitis* spp.	X	X	
Hickory	*Carya* spp.		X	
Honeysuckle	*Lonicera japonica*	X	X	

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[a] Condensed from, *Potential Best Management Practices to Control Sediment Non-point Source Pollution from Agricultural Land in North Carolina* (U.S. Soil Conservation Service 1978).

		Use		
Common Name	Scientific Name	Cover	Food	Windbreak
Japanese spurge	*Pachysandra terminalis*	X		
Lespedeza	*Lespedeza* spp.	X	X	
Lilturf	*Lirope spicata*	X		
Maiden cane	*Panicum hemitomon*	X	X	
Moss pink	*Phlox subulata*	X		
New Jersey tea	*Ceanothus americanus*	X		
Oak	*Quercus* spp.		X	
Pepper vine	*Ampelopsis arborea*	X		
Periwinkle	*Vinca minor*	X		
Pine	*Pinus* spp.		X	X
Porcelain vine	*Ampelopsis brevipedunculata*	X	X	
Privet	*Ligustrum* spp.	X	X	X
Redbud	*Cercis canadensis*			X
Red cedar	*Juniperus virginiana*		X	X
River birch	*Betula nigra*		X	X
Rose	*Rosa* spp.	X	X	
Rose acacia	*Robinia hispida*	X		
Rye	*Secale cereale*	X	X	
Scotch broom	*Cytisus scoparius*	X		
Showy forsythia	*Forsythia intermedia*			
Sorghum	*Sorghum bicolor*	X	X	
Spanish bayonet	*Yucca alnifolia*	X		
Sweet gum	*Liquidambar styraciflua*		X	X
Tag alder	*Alnus rugosa*	X	X	
Tall fescue	*Festuca arundinacea*	X		
Tartarian honeysuckle	*Lonicera tatarica*	X	X	
Thorny elaeagnus	*Elaeagnus pungens*	X		
Trumpet creeper	*Campsis radicans*	X		
Virginia creeper	*Parthenocissus quinquefolia*	X	X	
Wax myrtle	*Myrica cerifera*	X	X	X
Weeping lovegrass	*Eragrostis curvula*	X	X	
Wheat	*Triticum aestivum*	X	X	
White (ladino) clover	*Trifolium repens*	X	X	
Willow	*Salix* spp.	X		
Winged sumac	*Rhus copallinum*	X	X	
Winter creeper	*Euonymus fortunei*	X		
Winter jasmine	*Jasminium nudiflorum*	X		
Yaupon holly	*Ilex vomitoria*		X	X

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Pocosins are ecosystems endemic to the southeastern Coastal Plain of the United States. A characteristically sparse canopy of pond pine and an impenetrable layer of evergreen shrubs and vines are the hallmarks of this wetland type. Due to their hostile nature, pocosins have historically received little human attention or use. Recent changes in technology and human needs have made pocosins attractive targets for alteration to agriculture, forestry and peat mining operations. Unfortunately, little is known concerning environmental effects of pocosin alteration, the needs of pocosin wildlife, or the effects of pocosin alteration on adjacent ecosystems.

This document attempts to shed light on some of the problems of altering pocosins to human use by synthesizing the available literature on natural and modified pocosins (Part 1), and by outlining management options for wildlife in natural and modified pocosin settings (Part 2). Part 1 begins by defining pocosins, describing their distribution, and providing brief characterizations of associated ecosystems. The history of pocosin alteration is then discussed. Finally, the environmental effects of pocosin alteration are examined. Part 2 contains three sections that present practical alternatives for the management of regional landscapes, water, and wildlife.

17. Document Analysis a. Descriptors

Ecology, ecological succession, organic soils, peat, fire, savannahs, nitrogen, phosphorus, hydrology, wildlife

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Pocosin, palustrine wetlands, shrub bogs, wildlife management, pocosin alteration, peat mining

c. COSATI Field/Group

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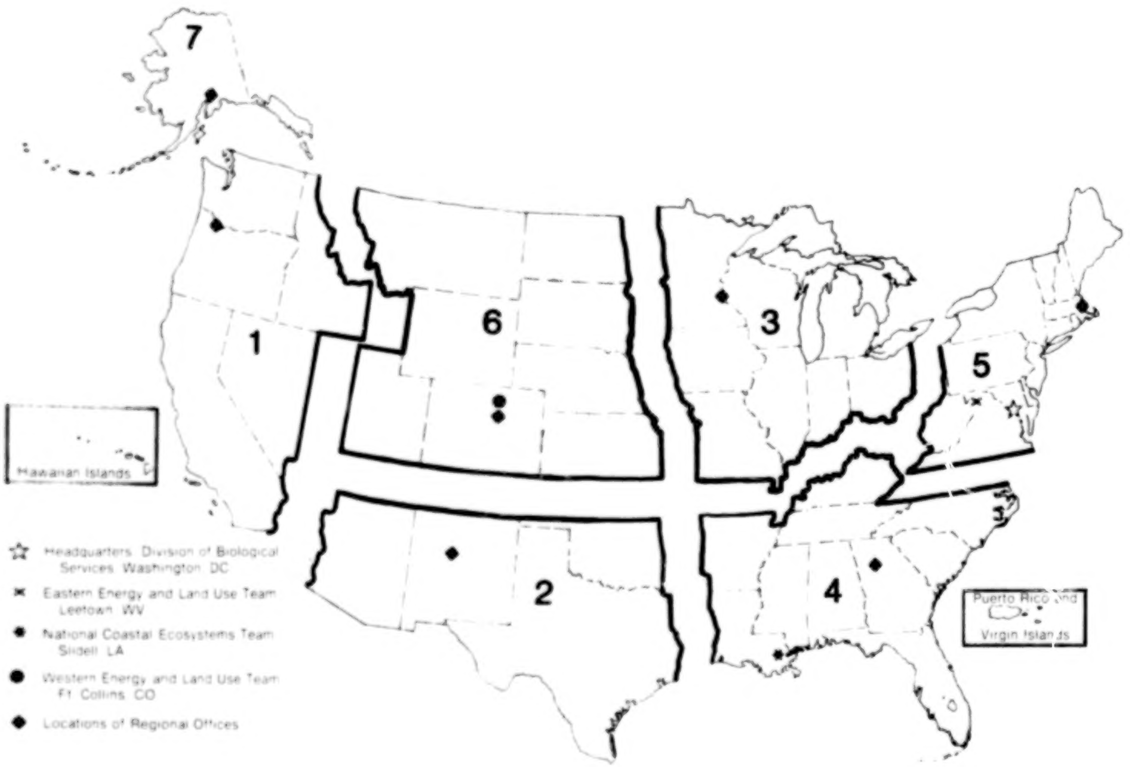
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Hawaiian Islands
Puerto Rico and Virgin Islands
☆ Headquarters, Division of Biological Services, Washington, DC
✖ Eastern Energy and Land Use Team Leetown, WV
● National Coastal Ecosystems Team Slidell, LA
● Western Energy and Land Use Team Ft. Collins, CO
◆ Locations of Regional Offices

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DEPARTMENT OF THE INTERIOR

U.S. FISH AND WILDLIFE SERVICE

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END

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